A SOCIO-ECONOMIC ANALYSIS OF THE POTENTIAL OF USING TRADABLE GRAZING RIGHTS FOR GRAZING RESOURCE MANAGEMENT IN ZIMBABWE'S COMMUNAL AREAS: A CASE STUDY OF BUHERA AND CHIDUKU COMMUNAL AREAS

BY

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DEDICATION

This thesis is dedicated to my daughters Palmy, Thandiwe and Naume and my son Ian Prince.

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ABSTRACT

The overall objective of the study was to carry out a socio-economic analysis of the potential of implementing tradable grazing rights as a market based mechanism for grazing resource management in Buhera and Chiduku communal areas. The major hypotheses that guided the research are: (i) communal area rangelands are open access and overgrazed; (ii) farmers' choice of grazing management policy option is significantly affected by household characteristics; (iii) large cattle herd households are willing to pay for grazing rights whilst small herd cattle owners are willing to accept payment of grazing rights; (iv) the mode of payment for grazing rights is similar between large and small herd cattle owners; (iv) (a) grazing resource allocation using TGR is more efficient and equitable than the status quo, (b) grazing resource management under TGR has positive environmental impacts, and (c) community level food self-sufficiency is higher with TGR than the status quo.

Rangelands in the communal areas of Zimbabwe are characterized by a lack of well-defined and exclusive property rights in grazing resource use. The most problematic common property conditions that are missing are: communally defined guidelines for resource use, exclusion mechanisms, and enforcement mechanisms. Of the study sites, the indicators reflect that Matsika and Nerutanga are not yet overgrazed whilst Gaza and Chiduku are overstocked by 29% and 35% respectively. All the study sites seem to have open access to grazing resources.

An assessment of alternative grazing resource management policies shows that TGR are the third (43.3 %) most preferred grazing policy after the individualization of grazing (67%) and grazing schemes (49.5%). The least preferred options are fodder production (17%) and the status quo (20%). TGR are supported by households with few or no cattle and by households in high potential agricultural regions and are opposed, particularly in the drier areas, by households with large cattle herds.

Overall, 75% of large herd owning households are willing to pay for grazing rights whilst 89% of the households with small cattle herds are willing to accept payment for TGR. Hence a market for grazing rights can be established in the communal areas.

Empirical estimation using a simple recursive bio-economic linear programming model shows that at the equilibrium price (i) TGR are more cost-effective than the status quo. The community net present values are 13%, 5%, 5% and 1% higher in Gaza, Nerutanga, Matsika and Chiduku respectively. (ii) Under normal rainfall conditions TGR results in reduced grazing pressure by 21%, 8%, 5% and 3% in Nerutanga, Gaza, Matsika and Chiduku respectively. It is only in Nerutanga that TGR at equilibrium price are sufficient to reduce grazing pressure to within the carrying capacity of the rangeland. (iii) The food self-sufficiency index of LH households in Gaza and Chiduku decrease by 8% and 4% respectively with TGR whilst for SH households across survey sites it increases by between 4 to 8%.

If TGR are going to be implemented there is need for: (i) development of a legislative framework paying particular attention to the initial allocation of grazing rights, and the creation and maintenance of a grazing rights registry; (ii) institutional development for grazing resource management backed by effective administrative and policing systems that ensure compliance, fairness in grazing resource allocation and that can preside over and manage resource-based conflicts; (iii) collective action for grazing control at the community level; and (v) long-term security of grazing rights to encourage investment in activites that are dynamically efficiency. Finally, TGR, if legally recognized, can be viewed as an asset that can be used as collateral for loans at the banks by the smallholder farmers.

TABLE OF CONTENTS

DEDICATION III

ACKNOWLEDGEMENTS IV

ABSTRACTV

LIST OF ACCRONYMS XV

CHAPTER I: INTRODUCTION, BACKGROUND, PROBLEM STATEMENT AND STUDY OBJECTIVES 1

1.0 INTRODUCTION 1
1.1 DEFINITION OF THE PROBLEM 3
1.2 APPROACH TO THE PROBLEM 3
1.3 OBJECTIVES OF THE STUDY 6
1.4 ORGANIZATION OF STUDY 7

CHAPTER II: AGRICULTURE AND LIVESTOCK PRODUCTION IN ZIMBABWE: AN OVERVIEW 9

2.0 INTRODUCTION 9
2.1 BACKGROUND 9
2.2 LIVESTOCK PRODUCTION 11
2.2.1 Objectives of keeping cattle 13
2.2.2 Constraints to cattle productivity 14
2.3 A HISTORICAL OVERVIEW OF THE GRAZING LAND DEGRADATION 15
2.3.1 Post independence government livestock policy 18
2.4 PROPERTY RIGHTS AND GRAZING MANAGEMENT 19
2.4.1 Communal tenure and administrative systems 20
2.4.2 Legal, traditional and de facto rights to allocate land in communal areas 22
2.5 DESCRIPTION OF STUDY SITES 23
2.5.1 Rainfall patterns 23
2.5.2 Livestock production 24
2.5.3 Grazing pressure 25
2.5.4 Human population pressure 26
2.5.5 Grain production 26
2.6 SUMMARY 28

CHAPTER III: LITERATURE REVIEW 30

3.0 INTRODUCTION 30
3.1 PUBLIC GOOD NATURE OF GRAZING LANDS 30
3.2 THE PROPERTY RIGHTS PARADIGM 32
3.2.1 Property regimes 32
3.2.2 Distinguishing open access from common property resources 33
3.3 EXPLAINING THE PROBLEM OF OPEN ACCESS TO GRAZING RESOURCES 35

3.3.1 Social trap in grazing and the free rider behaviour *35*
3.3.2 The isolation paradox and independent choice *36*
3.4 INTER-TEMPORAL PREFERENCES 38
3.5 APPLICATIONS OF TRADABLE EMISSION RIGHTS 40
3.6 LINEAR PROGRAMMING AND BIO-ECONOMIC MODEL IN RENEWABLE RESOURCE MANAGEMENT 43
3.6.1 Application of LP models *45*
3.6.2 Bio-economic models *46*
3.6.3 Applications of bio-economic models *46*
3.7 SUMMARY 48

CHAPTER IV: ADAPTATION OF POLLUTION ABATEMENT CONTROL THEORY TO GRAZING: AN ANALYTICAL FRAMEWORK 49

4.0 INTRODUCTION 49
4.1 OPTIMAL LEVEL OF GRAZING 49
4.2 GLOBAL AND LOCAL OPTIMA IN GRAZING RESOURCE USE 51
4.3 POLICY INSTRUMENTS FOR SUSTAINABLE GRAZING RESOURCE MANAGEMENT 54
4.3.1 Criteria for evaluating environmental policies *55*
4.3.1.1 Cost-effectiveness 55
4.3.1.2 Fairness or equity 56
4.3.1.3 Dynamic efficiency 57
4.3.1.4 Enforceability 57
4.3.2 A comparative analysis of the cost-effectiveness of standards, taxes and tradable permits *58*
4.3.2.1 Standards 58
4.3.2.2 Taxes 61
4.3.2.3 Tradable grazing rights 64
4.3.2.4 A cost-effectiveness comparative analysis 67
4.3.3 Equity Issues *70*
4.3.3.1 Standards 70
4.3.3.2 Taxes 70
4.3.3.3 Tradable permits 71
4.4 MONITORING AND ENFORCEMENT 73
4.4.1 Information costs *73*
4.4.2 Contractual costs *74*
4.4.3 Enforcement costs *74*
4.5 SUMMARY 75

CHAPTER V: RESEARCH METHODS 77

5.0 INTRODUCTION 77
5.1 SITES SELECTION 77
5.2 QUESTIONNAIRE DESIGNING AND IMPLEMENTATION 78
5.3 SECONDARY DATA COLLECTED 80
5.4 SELECTION OF SAMPLE HOUSEHOLDS 80
5.5 ENUMERATOR SELECTION, TRAINING AND SURVEY IMPLEMENTATION 82

5.6 DATA ENTRY AND CLEANING 83
5.7 SUMMARY 83

CHAPTER VI: ARE COMMUNAL AREA RANGELANDS OVERGRAZED OR OPEN ACCESS OR BOTH? 84

6.0 INTRODUCTION 84
6.1 HOUSEHOLD DEMOGRAPHIC, EDUCATIONAL AND EMPLOYMENT CHARACTERISTICS 84
6.2 INDICATORS OF OVERGRAZING IN THE COMMUNAL AREAS 86
6.2.1 Trends in grazing pressure (1954 – 1999) *86*
6.2.2 Household response to crop and livestock pricing policies *92*
6.2.3 Perceptions towards adequacy of grazing resources *95*
6.2.4 Fodder production *96*
6.2.5 Household perceptions of the trends in milk, draft power crop productivity over time *97*
6.2.6 Grazing time preference *98*
6.3 AN INSTITUTIONAL ANALYSIS OF GRAZING RESOURCE USE 100
6.3.1 Design principles for common property resource management *100*
6.3.1.1 Clearly defined boundaries 101
6.3.1.2 Proportional equivalence between benefits and costs 101
6.3.1.3 Collective choice arrangements 102
6.3.1.4 Monitoring and enforcement 102
6.3.1.5 Graduated Sanctions 102
6.3.1.6 Conflict-resolution mechanisms 103
6.3.1.7 Minimal recognition of rights to organize 104
6.3.1.8 Nested enterprises 104
6.3.2 Institutional analysis results *104*
6.4 SUMMARY 107

CHAPTER VII: DETERMINANTS OF HOUSEHOLD CHOICE OF ALTERNATIVE GRAZING MANAGEMENT POLICY OPTIONS 109

7.0 INTRODUCTION 109
7.1 A MODEL OF FARMER PREFERENCE OF GRAZING POLICY 110
7.2 EMPIRICAL MODEL ESTIMATION 113
7.2.1 Tradable grazing rights *119*
7.2.2 Individualization of grazing *120*
7.2.3 Grazing schemes *121*
7.2.4 Taxation of all cattle *121*
7.2.5 Taxation of more than four cattle only *122*
7.2.6 Community grazing management *122*
7.2.7 Fodder production *123*
7.2.8 Current grazing practice *124*
7.3 A TEST OF UNIQUENESS OF GRAZING POLICY PREFERENCES 125
7.4 SUMMARY 129

CHAPTER VIII: ESTIMATING THE POTENTIAL IMPACTS OF IMPLEMENTING TRADABLE GRAZING RIGHTS ON CROP AND LIVESTOCK PRODUCTIVITY....132
8.0 INTRODUCTION.... 132
8.1 TESTING FOR BIASES IN HOUSEHOLD WTP AND WTA FOR TRADABLE GRAZING RIGHTS.... 133
8.1.1Testing for starting point bias.... 134
8.1.2 Testing for vehicle bias.... 136
8.1.3 Household WTP for TGR.... 137
8.1.4 Household WTA for TGR.... 139
8.2 PREFERRED MODE OF PAYMENT FOR TGR.... 141
8.3 ESTIMATING DEMAND AND SUPPLY FUNCTIONS FOR GRAZING RIGHTS.... 142
8.3.1 Elasticity of demand and supply.... 145
8.4 POTENTIAL IMPACT OF IMPLEMENTING TGR ON AGRICULTURAL PRODUCTIVITY... 147
8.4.1 Potential impact of implementing TGR on grazing pressure.... 148
8.4.2 Potential impact of implementing TGR on cattle herd performance.... 149
8.4.3 Potential impact of implementing TGR on plowing rates.... 150
8.4.4 Potential impact of implementing TGR on maize yields.... 151
8.4.5 Potential impact of implementing TGR on milk yields.... 154
8.5 SUMMARY.... 155
CHAPTER IX: ESTIMATING THE COST-EFFECTIVENESS, DISTRIBUTIONAL, ENVIRONMENTAL AND FOOD SECURITY IMPACTS OF TRADABLE GRAZING RIGHTS: A RECURSIVE BIO-ECONOMIC LINEAR PROGRAMMING APPROACH....157
9.0 INTRODUCTION.... 157
9.1 MODEL SPECIFICATION.... 157
9.1.1 Objective function.... 160
9.1.2 Herd composition and off-take rates.... 163
9.1.3 Herd performance parameters.... 164
9.1.4 Herd dynamics.... 165
9.1.5 Carrying capacity and stocking rate constraint.... 167
9.1.6 Milk production constraint.... 169
9.1.7 Draft power constraint.... 170
9.1.8 Maize production function constraint.... 171
9.1.9 Land constraint.... 173
9.1.10 Labor constraint.... 173
9.1.11 Budget constraint.... 176
9.1.12 Tradable grazing right constraint.... 176
9.1.13 Rainfall.... 177
9.2 RESULTS.... 180
9.2.1 Base results.... 180
9.2.2 Cost-effectiveness of TGR.... 181

9.2.3 Income Distribution with TGR *182*
9.2.4 Grazing Pressure *185*
9.2.5 Food Self-Sufficiency *187*
9.3 SUMMARY 189

CHAPTER X: STUDY SUMMARY, CONCLUSIONS, POLICY IMPLICATIONS AND AREAS OF FURTHER RESEARCH 190

10.0 INTRODUCTION 190
10.1 SUMMARY OF STUDY MAJOR CONCLUSIONS 190
10.1.1 Adapting Pollution control theory to grazing control *190*
10.1.2 Communal grazing resources are open access and overgrazed *192*
10.1.3 Household preference of alternative grazing management policy options . *193*
10.1.4 Household WTP and WTA for TGR *195*
10.1.5 Preferred mode of payment for TGR *196*
10.1.6 Potential impact of TGR on agricultural productivity *197*
10.1.7 Cost-effectiveness, equity, environmental and food security impact of TGR *198*
10.2 IMPLICATIONS FOR POLICY AND DEVELOPMENT PLANNING 199
10.2.1 Development of a legislative framework *199*
10.2.2 Institutional development for grazing resources management *201*
10.2.3 The need for collective action in grazing control at the community level ... *202*
10.2.4 Issues of the allocation of grazing rights *203*
10.2.5 Long term security of rights *205*
10.2.6 TGR and the creditworthiness of smallholder farmers *205*
10.2.7 Environmental groups and trade in grazing rights *206*
10.2.8 Polluter pays principle and trade in grazing rights *207*
10.2.9 Monitoring and enforcement *207*
10.3 AREAS OF FURTHER RESEARCH 208

REFERENCES 211

ANNEX 1: QUESTIONNAIRES 230

ANNEX 1.1: HOUSEHOLD INFORMATION AND GENERAL ATTITUDES TOWARDS GRAZING RESOURCE MANAGEMENT 230
ANNEX 1.2: CROP PRODUCTION AND UTILIZATION OF COMMON PROPERTY RESOURCES 238
ANNEX 1.3: HOUSEHOLD PREFERENCE OF ALTERNATIVE GRAZING MANAGEMENT OPTIONS 242
ANNEX 1.4: RULES OF GRAZING RESOURCE UTILIZATION 251

ANNEX II: FOREIGN EXCHANGE RATES, 1989 – 1999 256

ANNEX III: RECURSIVE LINEAR PROGRAMMING MODELS 257

ANNEX III.A: LINEAR PROGRAMMING MODEL FOR NERUTANGA 257
ANNEX III.B: LINEAR PROGRAMMING MODEL FOR GAZA 262
ANNEX III.C: LINEAR PROGRAMMING MODEL FOR CHIDUKU 267

ANNEX III.D: LINEAR PROGRAMMING MODEL FOR MATSIKA 272

LIST OF TABLES

Table 2.1: Distribution of Land for Zimbabwe's Agricultural Sector, 1990 10
Table 2.2: Land distribution by agro-ecological region, 1990 11
Table 2.3: Population pressure in relation to carrying capacity, 1980 13
Table 2.4: Rainfall trends by survey site, 1954 – 1998 24
Table 2.5: Rainfall distribution patterns by survey site 24
Table 2.6: Trends in cattle numbers by survey site, 1954 - 1999 25
Table 2.7: Trends in the area under grazing by survey site, 1954 - 1999 26
Table 2.8: Estimated human population density (people per Sq. Km) by survey site: 1954 – 1999 27
Table 2.9: Trends in maize yields (t/ha) by survey site, 1954 - 1998 27
Table 3.1: Gain-loss table for the prisoners' dilemma game 36
Table 5.1: Stratification of study population and sample households by cattle ownership by survey site 82
Table 6.1: Demographic, educational and employment characteristics of household heads by survey site 85
Table 6.2: Mean farm size and area under fallow by survey site 86
Table 6.3: Trends in stocker days per ha per year (1954 – 1999) by survey site 89
Table 6.4: Mean number of cattle owned*, the number of cattle owners and the total number of cattle owned by sample households by survey site 91
Table 6.5: Percent Cattle Owners Indicating Major Reasons for Selling Cattle by Survey Site 93
Table 6.6: Percent Cattle Owners Indicating Response to an Increase in Cattle Prices by Survey Site 94
Table 6.7: Percen Cattle Owners Indicating Response to An Increase in Crop Yields or Prices on Tillingness to Sell Cattle by Survey Site 94
Table 6.8: Percent households+ indicating the degree of overgrazing by survey site 95
Table 6.9: Percentage households attributing the decline to milk, draft power and crop productivity to overgrazing by survey site 98
Table 6.10: Percent distribution of household grazing time preference by cattle herd size 99
Table 6.11: Presence of design principles for grazing resource management by survey site 105
Table 6.12 Percentage households indicating the presence of rules governing grazing resource utilization by survey site 105
Table 7.1: Description of Dependent Variables for Probit Model Estimation 114
Table 7.2: Explanatory Variables for Alternative Grazing Policies 116
Table 7.3: Maximum Likelihood Estimates of Probit Models of Household Preference of Alternative Grazing Management Policy Options 118
Table 7.4: Maximum Likelihood Estimates of the Impact of Supporting Alternative Grazing Policies on the Probability of Supporting a Given Grazing Policy 127
Table 8.1: Testing for starting point bias for WTP for grazing rights by Survey Site ... 135
Table 8.2: Testing for starting point bias for WTA for grazing rights by Survey Site... 135
Table 8.3: Testing for vehicle bias for WTP for grazing resource use 136

Table 8.4: Reasons for Not WTP for Grazing Rights by Large Herd HH by Survey Site 137
Table 8.5: Mean Household MWTP (USD) for Grazing Rights by Selected Household Characteristics by Survey Site 139
Table 8.6: Reasons for Not WTA for Grazing Rights by Small Herd HH by Survey Site 140
Table 8.7: Household MWTA (US$) for Grazing Rights by household characteristics by survey site 141
Table 8.8: Percent Households Preferring Mode of Payment for TGR by Herd Size and by Survey Site 142
Table 8.9: Community Demand and Supply Functions for TGR by Survey Site........ 144
Table 8.10: Herd Characteristics at Equilibrium Price by Survey Site 148
Table 8.11: Herd performance with and without TGR by Survey Site 150
Table 8.12: Estimated fertilizer application rates+ (kg/ha) by Survey Site 152
Table 8.13: Maize yield functions parameters by Survey Site 153
Table 8.14: Potential maize yields (kg/ha) with and without TGR by herd size category by Survey Site 153
Table 8.15: Milk yield (liters per lactation) functions by Survey Site 155
Table 8.16: Potential milk yield (liters per lactation) with and without TGR by Survey Site 155
Table 9.1: Linear Programming Model Exogenous Variables and Constraints Parameters 179
Table 9.2: Linear Programming Base Results and Comparable Survey Results........ 180
Table 9.3: Five-Year Average Percent GM With and Without TGR accruing to SH households by Survey Site 183
Table 9.4: Percentage Change of the Average GM per Household with TGR at Equilibrium by Household Category by Survey Site........ 184

LIST OF FIGURES

Figure 4.1: Marginal damage to pasture due to overgrazing 50
Figure 4.2: Global and local optima in external cost theory of grazing 53
Figure 4.3: Effect of high enforcement costs on optimal grazing level 58
Figure 4.4: Optimal grazing level of a standard 59
Figure 4.5: Cost-effectiveness property of a standard 61
Figure 4.6: Optimal grazing level with a tax 62
Figure 4.7: Taxes and cost-effectiveness 64
Figure 4.8: Cost-effectiveness of a tradable permit system 66
Figure 4.9: Cost-effectiveness of standards versus permits 68
Figure 4.10: Comparison of financial costs to herders of taxes and permits 69
Figure 6.1: Percent households indicating they have adequate grazing for their cattle .. 95
Figure 6.2: Percentage households indicating that milk, draft power and crop productivity have decreased over the period 1980 to 1995 by survey site 98
Figure 6.3: Percent distribution of household grazing time preference by survey site 99
Figure 6.4: Percentage cattle owning households complying with inter-community boundary rules by survey site 106
Figure 8.1: Percent Households not WTP nor WTA for TGR by Survey Site 138
Figure 8.2: Demand and Supply Functions for Grazing Rights by Survey Site 145
Figure 8.3: Percent decrease in the number of days taken to plow a hectare with TGR versus the status quo 151
Figure 9.1: Cattle-Crop Production Linkages 160
Figure 9.2: Expected Overall NPV With and Without TGR by Survey Site 182
Figure 9.3: Percentage Change in the Expected NPV with TGR at Equilibrium Price by Household Category by Survey Site 183
Figure 9.4: Five-Year Average GM per Household (USD) by Household Category by Survey Site 184
Figure 9.5: Five-Year Average Grazing Pressure Index With and Without TGR by Survey Site 185
Figure 9.6: Percentage Change in Average GP with TGR at Equilibrium by Survey Site 186
Figure 9.7: Grazing Pressure With and Without TGR over Time by Survey Site 186
Figure 9.8: Five-Year Average Grain Self-Sufficiency Index With and Without TGR by Household Category by Survey Site 188
Figure 9.9: Percentage Change in the Average Grain Self-Sufficiency Index with TGR at Equilibrium by Household Category by Survey Site 188

LIST OF ACCRONYMS

AREX	Agricultural Research and Extension
C.S.O.	Central Statistical Office
CA	Communal Areas
CGM	Community Grazing Management
CPR	Common Property Resources
GDP	Gross Domestic Product
GM	Gross Margin
GP	Grazing Pressure
GS	Grazing Scheme
HMACH	High Marginal Abatement Cost Household
IOG	Individualization of Grazing
LH	Large cattle herd households
LMACH	Low Marginal Abatement Cost Household
LP	Linear Programming
LSCS	Large Scale Commercial Sector
LTA	Land Tenure Act
MAC	Marginal Abatement Cost
MC	Marginal Cost
MCC	Marginal Cost of Consumption
MDC	Marginal Damage Cost
ME	Metabolizable Energy
MLAWD	Ministry of Land Agriculture and Water Development
MR	Marginal Revenue
MSC	Marginal Social Cost
MTPR	Marginal Time Preference Rate
MWTA	Maximum Willingness to Accept
MWTP	Maximum Willingness to Pay
NLHA	Native Land Husbandry Act

NPV	Net Present Value
NR	Natural Region
RTP	Rate of Time Preference
SH	Small cattle herd households
SPSS	Statistical Package for Social Sciences
SR	Stocking Rate
TAC	Total Abatement Cost
TGR	Tradable Grazing Right
USD	United States Dollar
VIDCO	Village Development Committee
WADCO	Ward Development Committee
WTA	Willingness to Accept
WTP	Willingness to Pay

CHAPTER I: INTRODUCTION, BACKGROUND, PROBLEM STATEMENT AND STUDY OBJECTIVES

1.0 INTRODUCTION

The structure of agricultural production in Zimbabwe is characterized by the existence of four distinct types of land tenure and farming systems: Large-scale commercial, small-scale commercial, smallholder and resettlement farming areas (Rukuni, 1994a). The government holds title to resettlement land and extends annually revocable permits to individual settlers (Rukuni, 1994b). The communal areas cover 42 percent of Zimbabwe and cater for about 55 percent of the population on individual arable holdings of between two to four hectares[1]. Although the state has *de jure* tenure, individuals are granted use rights of cropping land and key resources such as grazing, forests, forest products and water are accessed communally (Murombedzi, 1990). This thesis is concerned with the management of grazing resources in the communal areas.

Evidence from a number of sources indicates that the communal area rangelands are overgrazed (Ndlovu 1990; Clatworthy et. al. 1986; Rukuni 1985; Murombedzi 1990). The problem of overgrazing arises from a combination of the following factors:

i. In many communal areas, human and livestock numbers are greatly in excess of carrying capacity. There is excessive settlement pressure in some 40 percent of the communal areas (Whitlow, 1980).
ii. With an increase in the human population there is a corresponding increase in the demand for timber for building, fuel for heating and cooking, combined with opening up of land in the grazing areas for cropping and settlement (Chinembiri, 1989; Clatworthy et. al. 1986). This has resulted in the depletion of both browse and grazing.
iii. Fodder production on arable land is generally not being practiced in the communal areas due to general land shortage and the absolute priority for food and cash-crop production during the cropping season (Chinembiri, 1989; Clatworthy et. al. 1986).

[1] With the accelerated land reform since 2000, these land distribution patterns have changed.

Crop residues from crop production - which are basically of low protein content - are insufficient to support the large communal herd (Guveya, 1995). The majority of communal farmers do not use purchased supplementary feeds for protein, minerals or concentrates due to lack of finance and the non-viability of using these feeds given the low returns to commercial beef and milk production from the cattle herd (Guveya and Chikandi, 1996).

iv. Access to grazing is seen as unrestricted; exploitation of communal grazing land by privately held livestock means that a "tragedy of the commons" is inevitable (Rukuni, 1994a; Barnes, 1978). Common access to rangeland resources appear to have failed to ensure accountability in the utilization of the grazing resources. Open access to grazing resources seem to be the main reason for poor livestock performance and grazing land degradation in communal areas (Masomera, 1997; Guveya and Chikandi, 1996; Rukuni, 1994a; Cousins, 1990).

One solution to the perceived overgrazing problem have been to control stock numbers, restricting access to communal rangeland by means of fences, and management by means of rotational grazing under a system of grazing schemes (Cousins, 1987). Evidence shows that the implementation of grazing schemes has not been successful in reducing overstocking in the communal areas (MLAWD, 1992). This has been mostly due to the non-control of cattle numbers on the grazing lands. Extension officials have been determined to convince livestock owners to give up their “irrational” beliefs and aim instead at commercial production of meat and/or milk, and breeding programmes to upgrade the indigenous stock (Scoones and Wilson, 1989). Conservative stocking rates have been recommended for each of the five agro-ecological regions of the country. These stocking rates have been based on the need to stabilize beef/dairy production by preventing botanical changes in the rangeland thought to be indicative of degradation (Scoones, 1989).

1.1 Definition of the Problem

The problem motivating this study is the perceived inadequacy in the current tenure system for sustainable grazing resource management in the communal areas by the government and by right holders. For the government, the evidence of the inadequacies is the lack of increased livestock productivity and grazing resource degradation. For individual rights holders, inadequacies are manifested in the form of constraints preventing them from maximizing the value of their grazing resources. Economic and political institutions have failed to provide proper incentives for sustaining grazing resources because of two major interacting causes: short time horizons and failures in property rights. When access to the commons is not limited through some form of property rights, each farmer knows that the grass not grazed today will be gone tomorrow. Failure in property rights, in this case leads to short time horizons – high discounting or positive time preference.

Scoones (1990) and Muchena (1993) among others argue that communal area rangelands may not be overstocked. Their argument is based on the unreliability of using the beef cattle carrying capacity concept that is meant for commercial beef production. Also, in the communal areas cattle are provided with crop residues during the dry season and for this reason it is difficult to measure correctly the carrying capacity of the veld alone in communal areas. That the issue of overstocking has been alluded to since the 1920s and the cattle herd has increased many folds since then is enough to indicate that the carrying capacity for communal areas is not understood. It would seem logical that once the carrying capacity is attained, then from a biological point of view, the cattle herd will naturally stabilize or eventually decline.

1.2 Approach to the Problem

This thesis considers the efficiency, equity and sustainability of the current system of allocating grazing resources in the communal areas. Where resources have become depleted as in the case of grazing resources in the communal areas, this has been attributed to lack of private ownership of these common property resources (IFAD, 1995; Hartwick and Olewiler, 1986; Hardin, 1968; Gordon, 1954). In traditional economic analyses, recommendations for privatization of resource ownership were prevalent. However, the belief that private ownership will automatically solve problems of overexploitation cannot be supported on either theoretical or empirical grounds (Clark, 1973, 1976; Hartwick and Olewiler, 1986). Besides privatization is simply not feasible for communal grazing resources (Hitchcock, 1981). It is not technically feasible to give individual plots to farmers as these will be too small to ensure adequate feed for the household herd. Also, by individualization, farmers will not be able to strategically graze their cattle on different grazing locations during the different seasons of the year (Scoones and Wilson, 1989). With the increasing human population, isolation of grazing resource ownership, including the internalization of externalities is becoming more rather than less difficult. The reality is that exploiters of grazing resources have every incentive to impose major external costs to the public at large, and these externalized costs add up to the non-sustainability of grazing resource use.

Proposals to implement controls on cattle numbers are expensive and are not likely to be successful. The current system is open access and is not flexible and responsive to environmental changes, especially annual variables like rainfall and herbage availability. Hence there is need for a new system for grazing resource management. The Livestock Development Policy proposed the use tradable grazing rights (TGR) as one alternative (MLAWD, 1992). A system of TGR has not been analyzed and tested anywhere else in Africa. For purposes of this study, the proposed system of TGR is essentially an adaptation of the tradable permit system used for pollution control in developed countries.

TGR are a mechanism to internalize the externalities imposed by individually owned cattle on communally owned grazing. They serve to separate communal interest, in the improvement of grazing, from the interest of the individual in using that grazing. There are two potential and equally important versions to tradable rights for the communal areas. First, each community household would be allocated grazing 'shares' or grazing 'rights' that would be the right to graze a certain maximum number of livestock units. The total number of livestock units permitted would equal the locally determined carrying capacity. Thus, the household has a limited, but guaranteed right of access to grazing. Should the household possess insufficient livestock, this right can be sold or leased on an annual basis to other community members whose cattle exceed the initially allocated shares. In this way a price for grazing, which does not exist under traditional arrangements, would be established. All cattle owners with excess cattle and are unable to secure grazing for their cattle for that particular year or over a specified number of years, will have to destock their excess cattle. In this way overstocking and hence veld degradation would be avoided. With the legal backing of the central government, the local community may put into place a mechanism for ensuring that additional cattle above the stipulated number are actually de-stocked.

Second, instead of the trade in grazing rights only occurring within a single community, it could also occur between or amongst communities. Given the biophysical characteristics of a community in a given season, the maximum number of cattle that could be grazed is determined. The number of cattle over and above the set limit could be grazed in a nearby community who would require more cattle to meet their stocking quota. During drought periods, grazing permits could even be sought from distant communities to reduce on serious veld degradation and the related cattle mortalities.

The key question that arises is what are the socio-economic impacts of adopting or implementing TGR as a grazing management policy? Since this is a policy that is still under consideration and whose concepts are new to communal management of grazing, the initial step is to assess the farmers' perceptions and attitudes towards the policy. An analysis of farmers' attitudes will aid in determining whether the policy can be developed further for adoption. To be workable, the grazing resource use policies must pass the test of institutional acceptability. They must be constitutional and legal. Unless their proponents are willing to work against uphill odds, they must be politically acceptable and not conflict with accepted cultural attitudes, customs and traditions or strong or widely held beliefs. Thus, the analysis will enable an assessment of the feasibility of implementing the TGR policy. Next, an analysis of household WTP and WTA for grazing rights is attempted. An analysis of household WTP for TGR enables the identification of potential free riding camps and an assessment of the establishment of a potential grazing rights market. Using a recursive bio-economic linear programming model, the thesis intends to show that it is possible to use TGR as an instrument to control cattle numbers on the communal area rangelands and that the use of tradable grazing rights is cost-effective, equitable, and environmentally sustainable.

1.3 Objectives of the Study

The overall objective of the study is to carry out a socio-economic analysis of the potential of implementing tradable grazing rights as a market based mechanism for grazing resource management. The specific objectives of the study are:

1. To adapt pollution abatement control theory to grazing rights.
2. Determine if communal area rangelands are overgrazed or open access or both.
3. To assess household preference of alternative grazing management policy options.
4. (a) To assess household attitudes towards use of tradable grazing rights for grazing resource control through assessing: household willingness to pay (WTP) and willingness to accept (WTA) for grazing rights and the preferred mode of payment for grazing rights,

   (b) To assess the potential impact of tradable grazing rights on agricultural productivity,
5. To assess the efficiency, equity, environmental impact and food security implications of adopting tradable grazing rights using a recursive bio-economic linear programming model.

Based on the above objectives, the major hypotheses of the study are:

1. From a theoretical stand-point, the tradable grazing rights approach to grazing management is more cost-effective, dynamically efficient, and equitable than standards and taxes;
2. (a) Access to rangelands in the survey areas is open access;

   (b) The survey areas rangelands are overgrazed;
3. Farmers' choice of grazing management policy options is significantly affected by household characteristics;
4. (a) Households are willingness to pay for grazing rights,

   (b) Households are willing to accept payment for grazing rights, and

   (c) The preferred mode of payment for grazing rights is similar between potential buyers and sellers of grazing rights;

(d) Grazing resource allocation using TGR results in improved agricultural productivity (plowing rates, crop yields, milk yields, and cattle herd performance),

5. (a) Grazing resource allocation using TGR is more efficient and equitable than the status quo,

(b) Grazing resource management under TGR has positive environmental impacts compared to the status quo, and

(c) Community level food self-sufficiency is higher with TGR than the status quo.

1.4 Organization of study

This study is organized into ten chapters. This chapter presented the study background, problem statement, objectives and hypotheses, and scope of study. Chapter 2 presents an overview of agricultural and livestock production in Zimbabwe. The chapter reviews the role and objectives of keeping cattle in the communal areas; the constraints to keeping cattle; and the tenure regime governing resource use. A description of the study sites with respect to rainfall patterns, livestock and crop production is provided. Chapter 3 presents a review of the theoretical aspects of grazing resource over-exploitation. In Chapter 4, a theoretical framework for assessing the efficiency, equity, and sustainability of using grazing rights is adapted from a review of pollution control theory.

Chapter 5 gives the research methods used for the study. The issues covered under the research methods include site selection, sampling procedures, questionnaire designing, enumerator selection and training, survey implementation and data entry. Chapter 6 presents an analysis of whether grazing resources in the communal areas are overgrazed, open access or both. In the process of answering this question, an analysis is made of grazing resource time preference and rules governing grazing resource use in the communal areas.

Chapter 7 analyzes farmers' choice of grazing management policy options and identifies camps of support for the alternative grazing management policy options. The determinants of grazing policy preference are assessed. Chapter 8 focuses on household WTP and WTA for tradable grazing rights. The chapter also analyses the preferred modes of payment if TGR were to be implemented as a policy for grazing utilization control. Based on the WTP and WTA for grazing rights, the supply and demand functions for tradable grazing rights (TGR) are derived for each of the survey areas. The potential impact of TGR at equilibrium price on cattle herd performance and crop productivity is assessed. Using a recursive bio-economic linear programming model, Chapter 9 provides an *ex ante* analysis of the efficiency, equity, environmental and food security impacts of TGR compared to the status quo. Chapter 10 draws out the major conclusions of the study and discusses the study implications for policy and development planning. In conclusion, areas of further research are then highlighted.

CHAPTER II: AGRICULTURE AND LIVESTOCK PRODUCTION IN ZIMBABWE: AN OVERVIEW

2.0 INTRODUCTION

This chapter gives an overview of agriculture and livestock production in Zimbabwe. Section 2.1 provides the background to the agricultural sector in Zimbabwe. Section 2.2 gives an overview of the livestock sector focusing on cattle production. The objectives of keeping cattle and the constraints to cattle productivity in the communal sector are reviewed. The livestock-crop interactions within the communal areas[2] are given. Section 2.3 provides a historical overview of the problem of communal area grazing management, current government policies concerning the livestock sector and the current role of livestock in the communal areas and how each of these contribute to the continued degradation of the grazing areas. Legal, administrative and tenure issues surrounding the communal areas grazing management are discussed in Section 2.4. The Chapter then provides a brief description of the agricultural characteristics of the study sites in Section 2.5.

2.1 Background

Zimbabwe is a landlocked country with an area of 39 million hectares. It lies in the semi-arid tropics of sub-Saharan Africa with a population of about 12 million people (C.S.O., 1992) and an overall estimated average population density of 34 people per square kilometer (Chenje, 2000). Zimbabwe's population is predominantly rural with 77 percent of the population living in communal areas and commercial farms (IIED, 1992; Zinyama, 1988).

The agricultural land is divided into Large Scale Commercial Sector (LSCS), Small Scale Commercial Sector, Resettlement Areas and Communal Areas. Table 2.1 shows the

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[2] The term communal does not refer to communal ownership of resources (Muchena, 1993), but merely to areas where traditional land rights have evolved, and these rights generally assign private usufruct of cropland. Grazing and woodland resources are held under the common property regime. The State retains *de jure* rights to all the resources except for wildlife resources in CAMPFIRE districts that are the legal property of the districts.

distribution of land amongst these sectors by 1990. The most important sectors are the Large Scale Commercial and Communal sectors. A Large Scale Commercial Farm is defined as one having 5 or more permanent employees, at least 25 hectares under crops or a minimum of 350 head of livestock (cattle, sheep, goats and pigs) (Muchena, 1993). In contrast, a Communal Area farm is small with an average of between 2 to 5 hectares of land, mainly employs family labour, and has an average herd of less than ten cattle plus a few goats. Unlike the commercial sector, there is no freehold title to land in the communal sector.

Table 2.1: Distribution of Land for Zimbabwe's Agricultural Sector, 1990

Sector	Area ('000 ha)	Percent
National and unreserved land	6 603	17.2
Communal Areas	16 683	42.7
Large Scale Commercial	12 542	32.1
Small Scale Commercial	1 367	3.5
Resettlement	1 758	4.5
TOTAL	**38 953**	**100.0**

Source: Masoka, (1994)

The distribution of land across agro-ecological/natural regions is given in Table 2.2. Of the total land area, only 16.6 percent is in Natural Regions[3] (NR) I and II, high agricultural potential areas, with the rest in NR III, IV and V, the low agricultural potential regions (Muir, 1994; FSRU, 1985). Only one-twelfth of communal areas is located in the high potential areas whilst the figure is one-third for the commercial sector.

The Zimbabwean economy is largely based on the production of primary commodities with the agriculture and mining sectors providing a large proportion of the country's exports. The highest contributor by value is tobacco (making 20 percent of the value of all exports). Other important export crops include cotton, sugar, coffee, tea and livestock products (C.S.O.,

[3] The country is divided into 5 natural regions (NR). NR I has the highest Agricultural potential; NR V has the lowest potential, suitable mainly for livestock production.

1990). Agriculture provides the mainstay of the economy with 73 percent of the labor force within this sector, and provides between 26 and 36 percent of total wage employment (Muir, 1994; IIED, 1992). Agriculture contributes less than 20 percent of the gross national product (GNP) in most years. During the period 1980 to 1990 agriculture contributed between 14 and 16 percent of the GNP (Muir, 1994).

Table 2.2: Land distribution by agro-ecological region, 1990

Agro-ecological region/Sector	I	II	III	IV	V	Total
National and unreserved land	0.3	0.9	2.1	6.5	7.4	17.2
Communal Areas	0.2	3.1	7.0	18.1	14.3	42.7
Large Scale Commercial	1.2	9.8	5.6	9.7	5.8	32.1
Small Scale Commercial	0.0	0.6	0.7	1.5	0.7	3.5
Resettlement	0.1	0.4	2.4	0.5	1.1	4.5
TOTAL	**1.8**	**14.8**	**17.8**	**36.3**	**29.3**	**100**

Source: Muir, (1994); FSRU, (1985)

The livestock sector plays an important role in the economy, providing food and generating export earnings. During the period 1965 to 1990, livestock products, particularly beef and dairy products, contributed between 17 percent and 31 percent of the total value of primary agricultural production (Muir, 1994; C.S.O., 1990). Livestock products that are exported include beef, dairy products (cheese and butter) and sheep. Small ruminants, especially goats, are generally reared for home consumption (Ndlovu, 1994; C.S.O., 1990) especially in the communal areas.

2.2 Livestock Production

The main livestock species kept in Zimbabwe are cattle, goats, sheep, pigs, poultry and donkeys. Cattle dominate both in terms of numbers and in their contribution to the economy. The large scale commercial sector (LSCS) keeps specialized breeds of cattle either for beef or for dairy production while the communal areas (CA) keep mixed and indigenous breeds mainly for draft power, manure, milk, meat, and transport services. Although the communal area cattle herd account for about 65 percent of the cattle population, its off-take for purposes of beef production is low (1 – 3 percent) because cattle are kept for multiple purposes (Ndlovu, 1994; Steinfeld, 1988; GFA, 1987). By contrast the off-take from the commercial sector is between 17 – 23 percent.

By 1989, Zimbabwe had an estimated 5.5 million cattle, 2.2 million goats, 0.45 million sheep, 0.22 million pigs, and 1.2 million poultry (Ndlovu, 1994). The livestock numbers[4] in the communal areas dramatically increased from 1.8 million in 1965 to 3.4 million in 1977, an increase of approximately 80 percent (Chigaru, 1984). After stagnating in the late 1970s, the communal cattle herd increased from approximately 2.9 million head at independence to approximately 4.4 million head in 1991, indicating an average annual growth rate of 3 percent (MLAWD 1992). During the period 1980 to 1990, the goat flock increased from 0.982 million to 2.6 million and that of sheep from 0.387 million to 0.6 million (MLAWD 1992). However, fluctuations were experienced primarily due to droughts. It is estimated that the size of the communal herd fell by 31 percent due to the 1991/92 drought (Tawonezvi and Zindi 1995).

The increase in livestock numbers went hand in hand with an increase in the human population, without concomitant changes in the size of available land. The trend has been one of increasing cattle numbers and decreasing grazing resources as a result of increasing settlements and increasing cropping to satisfy the food needs of a rapidly expanding communal area population. In many areas of the country, human and livestock numbers were greatly in excess of carrying capacity of these areas (Table 2.3). By 1980, all but a third of the communal lands had human and population pressure in excess of their carrying capacity. This population pressure is excessive in some 40 percent of the communal areas (Blackie, 1982).

[4] This includes cattle, goats, sheep and pigs.

Table 2.3: Population pressure in relation to carrying capacity, 1980

Pressure Class	Proportion of Communal Lands (%)
Balanced or none	32.7
2 times – some	29.8
3 times – great	12.9
4 times – extreme	11.7
5 times – desperate	12.9

Source: Whitlow J.R 1980, "Environmental Constraints and Population Pressures in the Tribal Areas of Zimbabwe", Zimbabwe Agric. J., 77. 4: 173-181: in Blackie (1982)

2.2.1 Objectives of keeping cattle

The low off-take rates from the communal sector are a result of the objectives of keeping cattle. Cattle are not kept for beef or dairy production which are profit oriented enterprises in the commercial sector. The objective of keeping cattle in the communal areas of Zimbabwe is not necessarily to maximize profits. Cattle are kept for wealth accumulation and/or for subsistence objectives. The wealth accumulation view is that when cattle prices are increased household supply to the cattle market decreases. This is because, it is suggested, the communal area household cash needs are limited. This behavior results in a backward bending or perverse supply curve, indicating that herders concentrate on the building up of large herds as store of wealth (Bembridge, 1980; Low, 1980; Doran, et. al., 1979). However, the supply curve is only perverse if cattle are considered only for beef production. This is not that simple if cattle are considered as an asset.

A number of authors have examined both the economic and social roles of cattle and their contribution to subsistence (Danckwerts, 1974; Theisen and Marasha, 1974; Steele, 1981; Sandford, 1982; Avila, 1987; GFA, 1987; contributors to Cousins, 1989; Steinfeld, 1988; Scoones, 1990; Barrett, 1987 and 1992). These studies emphasized the multiple functions of livestock and enumerated the reasons for keeping cattle as an input into crop production, consumption and social functions and as a relatively liquid and high return asset.

The studies show that access to stock correlates closely with arable production. The GFA study

(1987) found that those with large cattle herds could produce up to four times the amount of maize of those without cattle. The yield advantages of owning cattle on crop production arise mainly from the timeliness of plowing the fields, the application of manure to improve and/or maintain soil fertility and moisture retention (Gryseels et. al., 1986). The ownership of cattle also leads to an expansion of the area under cultivation. The area cultivated per household member can be 25 percent greater where animals are owned (Pingali et. al., 1987). Despite these advantages of owning cattle, in most communal areas, there is an overall shortage of draft animals. The GFA (1987) found 40-60 percent of the households holding less than four cattle. Overall, just over 50 percent of the communal population own cattle (Chinembiri, 1989).

With open access to grazing resources, the objectives of keeping cattle may not be fully realized as the performance of the cattle herd deteriorates over time. Due to the decrease in cattle productivity, crop productivity is also negatively affected. With proper grazing management using market-based mechanisms, it is suggested that overgrazing may be reduced and hence cattle and crop productivity may be restored and sustained.

2.2.2 Constraints to cattle productivity

The constraints to cattle productivity in the communal areas include overgrazing, insufficient feed supply, a limiting land tenure system (Muchena, 1993; Chinembiri, 1989; Hamudikuwanda, 1988), a shortage of both arable and grazing land and a lack of credit facilities. The shortage of land for grazing results from the encroachment onto grazing land for settlement and cropping as the human population increases (MLAWD, 1992; Clatworthy et. al. 1986; Rukuni, 1985).

The insufficient feed supply is in terms of both quantity and quality. The winter or dry season is the time when feed is in shortest supply. The lack of dry season feed is mainly attributed to overgrazing in the wet season which does not allow a sufficient carryover of grazing for the dry season. During the dry season, the feeds available are deficient in protein and energy (Chinembiri, 1989). Due to the low importance of commercial livestock production, there is little supplementary feeding of proteins and concentrates. The shortage in protein and energy results in animals losing weight, the conception and calving rates drop, milk yields drop and draft animals are too weak to plow efficiently.

The keeping of large herds is alleged to be encouraged by the communal land tenure system, which results in the overgrazing of the veld and in land degradation (Muchena, 1993; Chinembiri, 1989). With many cattle owners having each a small number of cattle grazing on the communal lands, it will not normally pay an individual farmer to use inputs (e.g. refraining from using grazing land at appropriate times, or cultivation of forage legumes on the pastures) to improve the communal veld. The benefits to using inputs would accrue to all cattle owners using the veld, while the costs would be incurred by the individual grazier (Crotty, 1980).

Since independence in 1980, severe droughts in the 1982 – 84 period, 1986/87, 1991-1993 and 2001/02 have significantly affected the livestock sector as a whole. Producers incurred heavy stock losses. Thus, drought is a major production constraint. In addition, there are limited credit facilities available to the communal areas farmers to develop their livestock (Moyo, 1989; Chinembiri, 1989). Where these are available, the conditions attached are not attractive. Either the interest rates are too high or they take no account of the communal area farmer's circumstances, e.g. the inability to use land as collateral due to the communal land tenure systems and small herd sizes.

2.3 A Historical Overview of the Grazing Land Degradation

The phenomena of land degradation due to overgrazing and the expansion of arable agriculture into previously designated grazing land, dates back from the creation of the Native Reserves (the now communal areas) which resulted in the concentration of people on marginal land[5]. Black farmers were forced to leave the occupied areas for the Native Reserves. For instance, between 1903 and 1913, the proportion of peasants that moved into the Native Reserves of Masvingo rose from 10 percent to 40 percent (Rukuni, 1990; Arrighi, 1970) thus, increasing the pressure on the land. Between 1908 and 1914, the British South African Company trimmed the Native Reserves to allocate more land for white settlers (Rukuni, 1990), thus further increasing

[5] The creation of the Native Reserves started from 1898 with an Order in the Council from the British government. The Reserves were basically allocated to the drier and remote parts of the country which were

pressure on the already marginal lands. During the early 1920s, due to increases in taxes and falling grain prices, smallholder farmers were forced to increase the land under cultivation to raise the required tax. By the end of the 1920s, this process had reached its peak and it was reported that the number of cattle in the Reserves was becoming too large and that so much land was put under cultivation (Murombedzi, 1990).

In the 1930s the colonial government started paying attention to the conservation problems of the Reserves. The colonial government saw the crisis of land or grazing degradation in terms of bad African methods of land preparation - use of the plow, and opening up of new land by the well-off class of plow owning farmers. "Peasants" saw it as a crisis brought about by low prices, government intervention in marketing and the increasing diversion of labor from productive into conservation works. According to the then government the policy solution was centralization[6] which was meant to oust this new entrepreneurial class and eventually to drive them out of the Reserve system altogether (Ranger 1985). With the acute soil erosion in the Native Reserves, in 1943, the colonial government passed a notice which required compulsory destocking in the more crowded Native Reserves (Rukuni, 1990). Although this measure was unpopular, compulsory destocking remained in force until the early 1960s.

After the end of World War II, colonial agriculture in Zimbabwe became a profitable venture. This necessitated the implementation of the Land Tenure Act (LTA) which led to the mass eviction of African 'squatters' from European land unless they entered into labor agreements with the white farmers. The result was a dramatic increase in the human and livestock population in the Reserves and a concomitant and inevitable rise in the rate and extent of resource degradation in the Reserves (Murombedzi, 1990).

Government attempts to undermine large rural entrepreneurs continued with the promulgation of the Native Land Husbandry Act (NLHA) in 1951 whose main objectives were: to introduce and

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considered unsuitable for white settlement (Rukuni, 1994a).

[6] Originally conceded as a measure by which a division was made between exclusively arable and exclusively grazing land, centralization became a means of redistribution of land in the reserves.

enforce private ownership of land in Native Reserves, to enforce conservation practices, and to regulate farming practices and stocking rates through the issue of grazing permits (Rukuni, 1990). The philosophy of the 'tragedy of the commons' was the basis for enforcing private ownership of land. It was hoped that by enforcing certain standards for farming, this would result in higher production and incomes. The design was to allocate an "economic unit" of 3.2 ha per household[7] in high rainfall areas, and 4.8 ha in low rainfall areas. Grazing permits were issued after calculating the carrying capacity of a Reserve. Households holding more than the standard number were obliged to de-stock. Those owning less than the standard number got a permit for existing numbers and could not increase on that number. Those not owning arable land were barred from owning grazing permits.

The conservation measures of the NLHA - drain strips, gully dams, contour ridges, and rotational grazing - were resisted by the smallholder farmers because it meant taking out of production land that was already not enough to guarantee even subsistence needs and farmers would spend most of their time attending to conservation works. In spite of all this, the most important reason farmers resisted the NLHA was that it required them to limit livestock numbers so as to curb overgrazing (Cliffe 1986). The concept of private ownership of land was rejected in the Native Reserves. The programme collapsed in 1961 and the NLHA was amended to allocate some grazing land to the increasing number of landless households (Rukuni, 1994a).

In the early 1970s a policy of community development was conceived in which the state gave recognition to some of the institutional realities, particularly the role of chiefs, while still attempting to achieve the technical and economic objectives of the NLHA. These ideas were incorporated in the Land Tenure Act (LTA) of 1970 which gave legal recognition to what became known as the Tribal Land Authorities in the Tribal Trust Land (communal areas). The grazing schemes of the early 1970s were a direct result of this policy (Tawonezvi and Zindi, 1995). The perceived benefits from the setting up of grazing schemes included improved livestock production from rotational grazing which would lead to better calving rates, improved

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[7] Only married men were allocated land.

animal off-take arising from increased numbers as well as better veld management and reduced degradation, improved access to draft power, decreased labor requirements for herding and an increase in the availability of labor for other farming operations. The grazing schemes were also expected to reduce the risk of irreversible environmental degradation resulting from the perceived overgrazing. Contrary to expectations, the grazing schemes were not as effective in reducing grazing degradation and in improving livestock productivity (MLAWD, 1992). This has resulted from the inability to exclude outsiders from grazing in the schemes (Cousins, 1989); and the non-control of livestock numbers on the veld.

2.3.1 Post independence government livestock policy

Arable expansion into grazing areas has continued almost unabated in post-colonial Zimbabwe. In 1981, a Ministry of Lands, Resettlement and Rural Development was established to implement a land reform program. The goal of the program was to resettle 162 000 families on land acquired from the white commercial farms over the three year period, 1982 to 1985. By 1990, only 52 000 families had been resettled (Rukuni, 1994a). Thus, the resettlement program obviously did not significantly relieve land pressure in the communal areas. This is especially so when one considers that employment in the non-agricultural sector did not increase at all while the population grew at an annual rate of around 2.9 percent (Tawonezvi and Zindi 1995).

The post-independence livestock development policy is largely a continuation of policies initiated since the 1920s. The assumptions underlying these policies as well as the prescriptions proposed to the perceived problems have shown similar continuity. First, livestock production in communal areas has been seen in terms of milk and meat production. To this end the encouragement of small ruminant goes hand in hand with farmers' objectives for increased meat production as well as milk from cattle. The Livestock Policy Statement (MLAWD, 1992) argues that improvement in the efficiency of livestock production will lead to improved off-take rates and levels of income. Among other things, this is expected to be achieved by conserving rangelands, control of livestock numbers and stocking rates, promotion of grazing schemes, and increased off-take rates. How the conservation of the rangeland and control of livestock numbers and stocking rates are to be achieved is not spelled out.

The government objective of increasing cattle off-take from the communal areas is in direct conflict with farmers' objectives. Steinfeld (1988) makes it clear that communal area farmers are not interested in reducing their cattle numbers by selling because they regard having cattle as an investment. When the external value (market value) of cattle rises, farmers regard this as an additional security as well as a form of increased wealth. It is therefore surprising that while the policy document acknowledges the functions of cattle based on recent research, and recognizes the low levels of output from the communal sector, it proposes to consider increased beef production from cattle as an important thrust of policy.

Secondly, another view which has been advocated is the one which sees the communal tenure system as the major constraint to sustainable livestock production. The rangeland is a common property resource with the right to its exploitation held by all members of a loosely defined community. It is argued that lack of accountability on the grazing resource in traditional communal rangeland has resulted in lack of commitment to improve grazing areas and its water resources. This in turn have led to mismanagement, land degradation and, consequently, poor livestock productivity (MLAWD, 1992). While the policy paper recognizes this problem of common property management, it only highlights the formation of grazing schemes and efficient use of the available livestock feed - mainly crop residues as the possible solutions to curbing the degradation of grazing areas. The policy document does not indicate how the problem of open access within a community can be resolved to ensure efficient and sustainable use of the range.

2.4 Property Rights and Grazing Management

Hardin's "Tragedy of the Commons" paradigm (Hardin, 1968) has been extremely influential in explaining communal resource use. Hardin argued that the private benefit of grazing an additional animal on a common range exceeds the private costs because the costs of maintaining the rangeland are shifted onto the group as a whole. This provides an incentive to over exploit and thus degrades the grazing resources. However, Hardin's argument of common property resource degradation only holds under open access regimes and not under well-regulated common property regimes (IFAD, 1995). Under common property regimes the use rights of individuals can be delimited and regulated such that over exploitation of the resources does not result (Ostrom et. al., 1994; Ostrom, 1990; Bromley and Cernea, 1989). Careful analysis of traditional tenure systems shows that they can be composite, with clear user rights for arable and residential land, as well as group rights for pastures, forests, wildlife, waterways and sacred areas.

Although common property may be a stable pattern of resource use in traditional societies, population growth, technological change, or rapid climatic change can destabilize traditional institutions. The breakdown of common property systems in Zimbabwe has led to serious overgrazing (Runge, 1981). Where common property rules break down or fail to evolve to fit changing conditions, several outcomes have been observed. The system either tends to the individualization of common property or to increased resource degradation as the property regime slips towards open access. With open access, no one exercises control over the grazing resources. Since the property rights to grazing lands are not conveyed to any single farmer within a community, no single farmer can exclude others from exploiting the grazing lands. There are few incentives to protect the resource or invest in it.

2.4.1 Communal tenure and administrative systems

The robustness of the communal tenure system, however, is dependent on the strength of the traditional institutions in place, and the degree to which state and other local government institutions interfere or supersede traditional rights and administrative process. After political independence, Zimbabwe maintained the colonial legacy of inadvertent undermining of indigenous tenure systems (Rukuni, 1994b). There has been pressure for land titling, even in the communal areas. This titling, it is assumed, is more compatible with the intensification and commercialization of agriculture. There is mounting evidence, however that land titling and registration programs have generally not yielded positive benefits (Rukuni, 1994a). Moreover, formal title does not necessarily mean an increase in tenure security. Rukuni (2000) suggests that community titles for common property resources, such as communal pastures, forests, or other marginal lands may need to be given. Such areas constitute an important safety net for the poor that may be particularly important in high-risk environments where alternative means of insurance are unavailable. The preservation of common property resources could be desirable from an equity perspective since privatizing these lands takes away a part of the social safety net for the rural poor. Providing a community title for these lands can protect communal rights from outside encroachment and prevent the poor from being excluded from communal property use (Rukuni, 1994a).

For any property regime to function it has to be backed by effective administrative and policing systems that ensure compliance (IFAD, 1995). Additionally, there has to be an authority system that ensures fairness in allocation of national assets and that can preside over and manage resource-based conflicts. If the authority system is weak, becomes rent seeking or breaks down, then resources cannot be managed sustainably and any property regime can degenerate into open access. The increasing land and natural resource-based conflicts being witnessed in Zimbabwe are fuelled in large part by the weakness of land and natural resource administration institutions (policies, laws), lack of clarity of roles of the responsible institutions and poor enforcement of existing laws and regulations (Moyo, 1995). The basic premise is that a property right denotes a set of actions or behaviour that an owner may not be prevented from pursuing (IFAD, 1995). The role of the state or where such authority has been devolved to the local leadership of a village is to protect such rights.

The fundamental issue concerning communal tenure relates to problems arising with respect to land allocation, natural resource management, access to resources including water and to conflicts between different social groups. There is much confusion surrounding authority to allocate land and/or approve leases and permits. The situation is compounded by the presence of numerous interest groups ranging from state, public enterprises, district councils, entrepreneurs, migrant workers and landless households all competing for land and natural resources. These competing demands also put pressure on the local institutions and limited financial resources with respect to control, regulations and planning.

2.4.2 Legal, traditional and *de facto rights* to allocate land in communal areas

The communal Land Act of 1982 vests ownership of communal land in the president. The act assigned land administration to district councils rather than chiefs and headmen (Bruce, 1990). This legal position was one of several swings of the pendulum. An attempt by government to assume control of land administration from traditional authorities under the Native Land Husbandry Act of 1951 failed (Scoones and Wilson, 1989), with *de facto* control shifting back to the chiefs and headmen by the early 1960s and full legal control of land restored to them by the Land Tenure Act of 1970 (Rukuni, 1994a). Traditional leadership structures were dismantled after independence. The political justification for this was the historical association of traditional leaders with colonial administration. During the early 1990s, the traditional leadership in Zimbabwe was reinstated but their land allocation role remained unclear and was challenged by both centralized and district bureaucracies and political institutions.

Highly centralized systems of government were judged as the most serious threat to tenure security for land users under all types of tenure in Zimbabwe (Rukuni, 1994b). This problem is more serious for state land occupied by communities under customary rights. Communities occupying such land have limited exclusivity of rights because state bureaucrats and related politicians also claim institutional authority over such land and in the worst of cases these state functionaries may be the *de facto* landlords. The Ministry of Local Government has responsibility for enforcing the state controlled system and often subordinates traditional institutions to the state bureaucracy.

Whilst it appears that the land allocation functions of the district councils may sometimes be carried out by ward development committees (WADCO) or village development committees (VIDCO)[8], formal delegations have not generally been made. In practice, to an extent which is unclear, chiefs and headmen continue to allocate land. Headmen are sometimes elected to positions in the VIDCOs, and it is not clear upon which source of legitimacy they are drawing

[8] The WADCO and VIDCO are structures of the local government into which districts were divided after independence. A VIDCO is approximately 100 households, six VIDCOs constitute a WADCO.

in making land administration decisions. Basically, traditional leadership through chiefs and headmen, responsible for the management of land and other natural resources, has been weakened by the political structure changes. It may be futile to expect the traditional systems to recover adequately to discharge the traditional roles effectively. For this reason, a new community structure, which builds on the existing structure and includes traditional leadership, is needed to manage common pool resources in the communal areas. Under this new system, there is need for clarification of who the responsible authority for land administration is.

2.5 Description of Study Sites

This section provides a description of the four communities of Matsika, Chiduku (in Chiduku Communal Area), Nerutanga and Gaza-Chifamba[9] (in Buhera Communal Area) that were the basis of the study. The two communal areas, Chiduku and Buhera, within which the study sites are located in Zimbabwe, were purposely selected as they have differing agricultural potential. Chiduku Communal area is 230 km East of Harare whilst Buhera Communal Area (CA) is 250 km South East of Harare. The two communal areas are approximately 120 km apart. The two study sites in Chiduku CA are in agro-ecological/natural regions II (Matsika) and III (Chiduku). Nerutanga and Gaza of Buhera CA are in NRs III and IV respectively.

2.5.1 Rainfall patterns

All sites are characterized by large fluctuations in rainfall over time, with the standard deviations around the mean annual rainfall over a 45-year period (1954 – 1998) being 250 mm, 200mm, 223 mm and 262mm for Matsika, Chiduku, Gaza and Nerutanga respectively. Across all sites, the mean annual rainfall over ten year periods is decreasing over time (Table 2.4). Although Nerutanga is classified as falling under agro-ecological or natural region III, the rainfall figures show that is has a favorable microclimate and thus receives rainfall similar to that of NR II.

The rainfall distribution pattern of the survey sites over the 45-year period is presented in

[9] Here-on shortened to Gaza.

Table 2.5. The probability of having less than 600 mm of rainfall per year is, as expected, highest in Gaza at 45 percent. The probability of having less than 600 mm of rainfall per year is similar between Chiduku and Matsika. As noted above, the rainfall distribution pattern of Nerutanga is similar to the one for Matsika with the probability of having at least 900 mm of rainfall per year being 39 percent.

Table 2.4: Rainfall trends by survey site, 1954 – 1998

	NERUTANGA NR III	GAZA NR IV	CHIDUKU NR III	MATSIKA NR V
Mean annual rainfall (mm)	775	610	715	764
Mean rainfall (mm) for period:				
1954 – 1960	883	670	808	850
1961 – 1970	684	593	651	726
1971 – 1980	899	711	815	822
1981 – 1990	760	554	677	754
1991 – 1997	641	513	623	664

Source: Meteorological Offices, Rusape and Buhera Center

Table 2.5: Rainfall distribution patterns by survey site

NERUTANGA		GAZA		CHIDUKU		MATSIKA	
Rainfall (mm)	Probability	Rainfall (mm)	Probability	Rainfall (mm)	Probability	Rainfall (mm)	Probability
452	0.11	96	0.02	372	0.02	318	0.02
567	0.14	256	0.11	448	0.16	451	0.11
617	0.02	449	0.27	534	0.12	532	0.16
742	0.16	541	0.14	653	0.16	644	0.09
837	0.18	652	0.16	742	0.21	751	0.11
930	0.14	749	0.20	844	0.16	845	0.16
1123	0.25	940	0.05	941	0.07	944	0.09
-	-	1039	0.05	1046	0.10	1168	0.26

2.5.2 Livestock production

The main livestock kept in the survey sites are cattle, goats and poultry. Of these, cattle are considered the most important followed by goats. It is notable that cattle perform significant roles of providing draft, manure, transport, security, cultural obligations and milk production and thus the desirability of every household to own a herd. These functions are of major significance to the communal farmer resulting in cattle raring for cash in most areas being a residual activity. Farmers tend to view the cattle component of their farming system in the short run mainly as an input into crop production and not as an enterprise on its own right.

A trend analysis of cattle numbers in the study areas shows that there is an increase in cattle numbers over time (Table 2.6). However, this increase is characterised with a fall in herd size per household, complemented by an increase in the number of households owning cattle (see Table 5.4).

Table 2.6: Trends in cattle numbers by survey site, 1954 - 1999

	NERUTANGA	GAZA	CHIDUKU	MATSIKA
Mean number of cattle for period:				
1954 – 1960	194	179	316	183
1961 – 1970	241	224	394	228
1971 – 1980	312	290	509	294
1981 – 1990	359	363	593	361
1991 – 1999	411	347	672	361
Annual cattle population growth rate (%)	2.61	2.16	2.64	1.94

Source: Rusape and Buhera District Council Data, 1999 with extrapolations from national level data

2.5.3 Grazing pressure

Table 2.7 shows the trends in the area under pasture across the survey sites. The most rapid decrease in the area under grazing is noted in Matsika and the least is noted for Nerutanga. This is a result of the smaller initial total area and a rapid increase in the area under cultivation in Matsika.

Given that the cattle herds are increasing (Table 2.6) and the area under grazing is decreasing (Table 2.7) over time across all survey sites, the implications are that forage availability is decreasing over time, hence grazing resources are becoming more and more overgrazed.

Lack of adequate feed and especially dry season feed, has probably resulted in weak and reduced draft power to service an increasing number of cultivators at the beginning of each cropping season leading to general delays in crop establishment.

Table 2.7: Trends in the area under grazing by survey site, 1954 - 1999

	NERUTANGA	GAZA	CHIDUKU	MATSIKA
Total Area (ha)[10]	1641	1688	2634	1873
Percent area under grazing for period:				
1954 – 1960	98.6	98.1	95.9	95.3
1961 – 1970	98.1	97.5	94.6	93.8
1971 – 1980	97.4	96.5	92.5	91.4
1981 – 1990	96.5	95.2	89.8	88.3
1991 – 1999	95.3	93.6	86.4	84.4
% Annual decrease rate in grazing land	0.08	0.11	0.23	0.38

Source: Rusape and Buhera District Council Data, 1999 with extrapolations from national level data

In the majority of communal areas of Zimbabwe, including the survey sites, there is no fodder production either on the range or individually, to supplement livestock feed. Nor is there the practice of purchasing livestock feeds for livestock feeding (except in the case of rearing chickens).

2.5.4 Human population pressure

Trends in population density are similar between Gaza and Chiduku then Nerutanga and Matsika (Table 2.8). Across all survey sites the population density has more than tripled since 45 years ago. The increase in population density has meant marginal land being brought under cultivation and an increase in the land for settlement. The result has been a decrease in the area under grazing over time (Table 2.7).

2.5.5 Grain production

Table 2.9 shows the trends in maize yields. Independence saw an improvement in the access

[10] Enumerators assisted by delineating the boundaries of the survey sites from base maps. The delineated maps were scanned and the resultant files were used to estimate the total area for each survey site using Map Maker Pro.

to inputs and favorable price incentives for agricultural output as reflected in an increase in maize yields after 1980, especially in the higher rainfall area of Matsika in NRII. However, this improvement in grain yields decreased during the period 1990 – 1997 because:

- the same period witnessed the 1992/93 drought and below average rainfall during the early 1990s and a drought in 1995, and
- the implementation of the Economic Structural Adjustment Program (ESAP) resulted in an increase in input costs which translated into lower input use and lower crop yields. The resultant low yields have implications on crop residue availability particularly during the dry season. The higher the grain yield, the higher the expected crop residue yield from the crop lands.

Table 2.8: Estimated human population density (people per Sq. Km) by survey site: 1954 – 1999

Period	NERUTANGA	GAZA	CHIDUKU	MATSIKA
1954 – 1960	8.1	11.5	11.9	7.1
1961 – 1970	10.7	15.2	15.7	9.4
1971 – 1980	14.9	21.2	21.9	13.1
1981 – 1990	20.2	28.6	29.6	17.7
1991 – 1997	26.9	38.1	39.4	23.6

Source: Rusape and Buhera District Council Data, 1999 with extrapolations from national level data

Table 2.9: Trends in maize yields (t/ha) by survey site, 1954 - 1998

Period	NERUTANGA	GAZA	CHIDUKU	MATSIKA
1954 - 1960	0.86	0.47	0.45	1.33
1961 - 1970	0.80	0.43	0.42	1.34
1971 - 1980	0.85	0.47	0.45	1.54
1981 – 1990	1.22	0.66	0.64	2.22
1991 – 1998	1.13	0.62	0.60	2.05

Source: Rusape and Buhera District Council Data, 1999 with extrapolations from national level data

An important practice in crop production, which has a bearing on the availability of cattle feed during the dry season, is that immediately after harvest, fields are opened for grazing of crop residue. This applies even if a household does not own livestock. The requirement that land holders should open up their fields for grazing by their fellow villagers has an important implication for the management of cropland. The collected crop residues are not available to build-up soil nutrients.

The villagers, through their chief and headmen, often govern the grazing lands. The community resources are managed for the good of the entire community. The management objective is to increase the benefits to the community in general, as opposed to individual members. Despite some institutional structure around grazing management, lack of well-defined and exclusive property rights, though not the single cause, is perceived as the major contributor to overgrazing in the survey sites.

2.6 Summary

The chapter presents an overview of: (i) the agricultural sector of Zimbabwe with an emphasis on the livestock sub-sector and (ii) the study sites. An overview of the livestock production characteristics of the survey sites is given. Livestock systems include cattle and goats as the major ruminant animals while non-ruminants include pigs and poultry. As is the case in almost all communal areas, livestock and crop production are closely integrated and compete heavily for resources, particularly land. Livestock, particularly cattle are kept mainly for their functions and intermediate products, i.e. draft power, milk and manure. Meat and cash are only of secondary importance. Cash is invariably more important with small ruminants i.e. goats and non-ruminants, i.e. poultry and pigs.

Due to the importance of cattle in the communal area farming systems, cattle populations are difficult to control as more and more farmers aim to increase their cattle holdings. Practically, every farmer would like to own and keep cattle. Because the communal areas are mostly in the low potential areas, with low and unreliable rainfall and frequent droughts, both grass/forage and crop production (including the quality) are low and supplies fluctuate widely within and between seasons. Very often land allocated to livestock is of very poor quality and has been steadily decreasing over time thus, aggravating the feed supply situation. On one hand, all grazing land is communally owned with little control over its use, thus making any improvement measures difficult or impossible to implement under the current grazing practices. On the other hand livestock are individually owned. With a combination of these factors overstocking is, therefore, an inevitable feature of the communal farming system.

The purpose of village grazing lands is to complement crop production by providing households with forage for livestock kept for draft power, manure, meat and milk for subsistence. No formal permission is required for putting livestock to pasture. The only requirement is residence in the village controlling the pasture. Hence, lack of well-defined and exclusive property rights, though not the only factor is a major contributor to the perceived overgrazing in the survey sites.

An overview of the study sites characteristics shows that the rainfall pattern across all sites is highly variable. It is clear that whilst cattle numbers are increasing over time, the area under grazing is decreasing due to the demand of land for settlement and cultivation. On average maize yields have increased over time with the most significant improvements noted after independence in 1980. However, the 1990s saw a decline in maize yields due to severe droughts and the reduced access to subsidized fertilizer and seed inputs.

CHAPTER III: LITERATURE REVIEW

3.0 INTRODUCTION

This chapter presents the literature review for the study. The issues covered are on the public nature of grazing resources (Section 3.1), the property rights paradigm and the distinction between open access and common property resources (Section 3.2), and the theoretical explanations of the overgrazing problem (Section 3.3). A review of the role of time preference in inter-temporal resource allocation is presented in Section 3.4. Section 3.5 provides some lessons learnt in the implementation of emissions tradable rights that may be useful in designing an implementation framework for tradable grazing rights. A review of the application of linear programming and bio-economic models in natural resources management is presented in Section 3.6. Section 3.7 concludes the chapter.

3.1 Public Good Nature of Grazing Lands

Grazing lands in the communal areas of Zimbabwe are public goods which are (1) non-excludable, and (2) congestible (Ostrom et. al., 1994; Weimer and Vining, 1989). When a good possesses the property of non-excludability, it is costly to exclude or limit potential beneficiaries (users) from consuming the good. For example, in the communal areas, fencing may be the ultimate physical means of excluding or limiting the number of potential beneficiaries from using natural pastures. To be effective, however, the fencing must be backed by a set of property rights that are feasible (in an economic and legal sense) within the legal system available to individuals in the local community (Weimer and Vining, 1989). The legal and economic feasibility of excluding or limiting use by potential beneficiaries is derived both from the physical attributes of the goods and from the institutions used in a particular jurisdiction.

Common property resource problems can be structural, where aspects of the good preclude economically feasible exclusion mechanisms, or institutional, where economically efficient exclusion mechanisms are feasible but the distribution of property rights precludes their implementation (Weimer and Vining, 1989). Grazing resources in the communal areas seem to fall in the second category. Institutional common property resource problems are usually not fundamentally market failures, rather they most often are due to the failure of government to allocate enforceable property rights.

Grazing resources in the communal areas are spatially stationary - ownership of grazing resources can be easily attached to ownership of land. Owners of the land could monitor effectively all aspects of ownership and consequently ensure exclusive use. Because of spatial stationarity there would be low monitoring costs and thus viability of enforcing exclusion and developing effective property right systems.

Grazing resources in the communal areas are congestible. A good is congestible if the marginal cost of consumption (MCC) can become positive beyond some level of consumption. Over the range where the MCC is zero, the amount of herbage consumed can be increased without reducing the consumption benefits of other herders. In this case, a few herders are able to graze their cattle without noticeably affecting the amount of herbage available to other herders. This is the case when the human and livestock populations in the communal areas are low and there are extensive grazing lands. Thus, during that period, although pasture is rivalrous in consumption, for practical purposes there is no environmental damage. Over the range where the MCC is zero, it does not mean the marginal costs of production are zero because the farmer still has to herd their cattle, construct cattle kraals, store crop residues for dry season supplementation and incur veterinary costs in producing cattle.

In the range where the MCC is positive, as the number of herders and cattle increase on the rangelands, beyond some level, the herders begin to interfere with each other, so that each animal must graze longer to get the same amount of feed per day. There may be disputes over access to particular sites and herders may have to get up earlier to ensure they access the good grazing areas before others do. Hence the benefits of other herders from utilizing grazing lands are reduced. The reduction in herder benefits can be thought of as costs. Because these costs accrue to all cattle owners of the local community, they are referred to as the marginal social costs of consumption.

3.2 The Property Rights Paradigm

3.2.1 Property regimes

Grazing resources can be subjected to four different property regimes: state, private, common (*res communis*) and open access (*res nullius*). The relevant concepts analyzed by Bromley (1991) and Bromely and Cernea (1989) are used to characterize each regime, as follows:

- If resource users have the duty to observe rules and norms of use/access determined by a government institution that has the right of its management, then the grazing is state property.
- If the herders have the right to decide individually on socially acceptable uses of the resource, even though they have the duty to abstain from destructive uses, the exploitation regime is deemed private property.
- If the State has allocated property rights to a well-defined group of herders who have specific rights and duties with respect to the rates of resource use, then the exploitation regime is of common property (*res communis*). This situation implies a necessary but not sufficient condition for success in the optimal allocation of a resource (Seijo et. al., 1998). This is because common property regimes consider exclusion of non-participants and specific duties to resource users. The efficiency of alternative management actions imposed by the management authority, and the clear specification of rights and duties for the owners, are critical to avoid open access to grazing resource use.
- Under open access (*res nullius*) conditions, the resource as property does not exist. Two situations arise: (1) unrestricted access to the resource and (2) generation of externalities between resource users. The regime fails to lead to optimal resource allocation, and this constitutes a sufficient condition for resource overexploitation (Anderson. 1977; Hannesson, 1978). With respect to grazing resources in the communal areas of Zimbabwe, the question is whether the grazing resources are common property or open access. This question is explored in Chapter 6 of this thesis.

To have an optimal allocation of natural resources under any property regime other than that of open access, non-attenuated property rights need to be specified. Those rights must be (Tietenberg, 1994; Randall, 1981; Schmid, 1987):

- Completely specified in terms of the rights that accompany the property over the resource, the restrictions over those rights, and the penalties corresponding to their violation.
- Exclusive, so that the person who has those rights will also be responsible for any retributions and penalties corresponding to the use of the natural resource,
- Transferable, in order to have those rights in the hands of those who have the capacity to convey them to the highest use value, and
- Effectively enforced, because a non-policed right becomes an empty right.

3.2.2 Distinguishing open access from common property resources

Following Hardin, (1968) a number of authors argue that the mere existence of common property rights over a scarce resource will lead to over-exploitation of the resource because of the failure to internalize the social costs of grazing the last head of cattle (Demsetz, 1967; Cheung, 1970; Furubotn and Pejovich, 1972). They argue that the enforcement of private use-rights to the resource will yield internalized costs to each user equal to benefits in total and at the margin. However, in their analyses these authors fail to distinguish between situations of open access (in which the main difficulty is unrestricted entry) and those of managed common property (which implies access by a well defined community subject to given rules of resource use) (Runge, 1981). Under common property regimes the use rights of individuals can be delimited and regulated such that over-exploitation of the resources does not result.

As an institution, common property is distinguished from free and open access where there are no rules regulating individual grazing access (Ciriacy-Wantrup and Bishop, 1975). Often, what appears to the outside observer to be open access may really involve tacit cooperation by individual users according to a series of rules. This is common property. Empirically, it is important to distinguish between open access and common property if appropriate policy is to be formulated. The problems of open access arise from unrestricted entry. Problems of common property pertain to use-rights by a group of a given size.

Runge (1986) argues that overgrazing is not the result of common property institutions, but is because of the inability of interdependent individuals to coordinate and enforce actions in situations of strategic interdependency. Common property arrangements are potentially equitable, economically efficient, and ecologically appropriate and sustainable. Swallow (1990) showed that in a common property regime: (1) no single individual has exclusive rights to the use of the commons, (2) group members have secure expectations that they can gain access to future use of the resource, (3) there are functioning membership criteria, (4) there are communally defined guidelines for resource use, and (5) there is an enforcement mechanism for punishing deviant behavior. Swallow states that relatively few African rangeland situations satisfy all the conditions for common property, and conditions (4) and (5) appear to be the most problematic. By adopting tradable grazing rights (TGR), conditions 4 and 5 that are missing in grazing resource appropriation in the CAs may be met.

Lawry (1990) distinguishes between a "minimum" definition of common property and those arrangements needed to regulate resource use in a more intense manner. A "minimum" definition is met where group membership rules are well defined and non-members are excluded from access to common resources. Lawry suggests that these arrangements have often been adequate when population pressure on resources was not excessive, but that intensified controls and their enforcement became necessary with population growth, technological change, national economic integration and the decline in political legitimacy of local institutions. The integration of local economies into larger systems, and the consequent decline in the importance of local political institutions has meant that the ability of local groups to defend their commons from the encroachment of outsiders (i.e. the assertion of "minimum" common property rules) has been undermined. Traditional authorities and local elites are no longer in a position to enforce rules. In Zimbabwe, state and local government intervention has reduced the efficacy of the enforcement of traditional norms and rules by chiefs and headmen.

The breakdown of common property, due to the destabilization of traditional institutions, not only in Zimbabwe, but also in the Sahel and other countries of Southern Africa has led to serious overgrazing (Runge, 1981; Picardi, 1974; Glantz, 1977). Where common property rules break down or fail to evolve to fit changing conditions, at least five processes have been recognized: (i) resource privatization through the individualization of common property (Vedeld, 1992); (ii) state intervention through the regulation of size of the herd kept on the veld; (iii) implementation of community-based management systems (Berkes, 1989; Smith and Berkes, 1991); (iv) mixed strategies based on a combination of the above schemes (Defeo, 1993a, 1993b; Seijo, 1993; Castilla, 1994; Castilla et al., 1998); or, (v) there may be increased resource degradation as the property regime slips towards open access (Vedeld, 1992). To assess if grazing resources in the communal areas are open access or not, an analysis will be made of the minimum requirement of exclusion of outsiders for a resource to be common property. An analysis will also be made on how exclusion is defined within the group of herders in a village.

3.3 Explaining the Problem of Open Access to Grazing Resources

3.3.1 Social trap in grazing and the free rider behaviour

Without an agreement on the number of cattle to keep, the main result of a single herder's reduced herd size, is to lower the extraction cost of other herders without necessarily increasing own benefits. Consequently, each herder will increase their number of cattle on the veld and thus contribute to destroying the grazing resource, an undesired long-run result for all herders involved. This constitutes a social trap in grazing management because the micro-motives of an individual herder in the short-run are not consistent and compatible with the macro-results that the community desires in the long-run (Schelling, 1978). The short-run herders' micro-motives consist in grazing as many cattle as possible in order to increase their marginal benefits, while the long-run desired macro-results may involve achieving the optimum sustainable yield. Uncertainty of future grazing availability determines that long-run results are usually dominated by marginal benefits in the short-run. Seijo et. al., (1998) argue that the sustainable yield of grazing resources, given certain inter-temporal preferences of resource use, will be an attainable goal only when the number of herders is limited by some kind of effort regulation and the herders act in concert.

A number of authors argue that the size of the group of herders is a relevant factor affecting the avoidance of this social trap (Seijo et. al., 1998). If the group is large, a herder may be an unintentional free rider or non-contributing user when he/she cannot avoid the micro-result (grazing collapse) because he/she cannot be sure that the behavior of other herders will sustain resource yield. This kind of user is usually found when there is no voluntary collective action by most community members to prevent resource depletion, and also when uncertainty exists about stock abundance (which is the usual case). When the group is small, exclusion costs are not necessarily lower, but the non-contributing user could be easily identified, therefore reducing the number of free riders (Schmid, 1987).

3.3.2 The isolation paradox and independent choice

The familiar prisoners' dilemma game can be used to explain the problem of open access being experienced in the communal areas. The prisoners' dilemma, when generalized to more than two actors, is known as the isolation paradox (Runge, 1981). With this paradox, the basic result is that collective decisions by independent actors produce inferior outcomes, unless an enforceable rule from outside is brought upon the group.

The prisoners' dilemma is illustrated in the gain-loss table in Table 3.1. "Confess" or "not confess" represent the strategies open to each of the two prisoners. The ordered pairs indicate the number of years in prison that will result from a particular coincidence of choices. Assume the prisoners are interrogated independently. Both know that if neither confesses, they will receive short sentences and spend a year in prison (1, 1); if one confesses and turns state evidence they will be released, and the other will receive a heavy term of ten years (0, 10), (10, 0). If both confess, each gets five years (5, 5).

Table 3.1: Gain-loss table for the prisoners' dilemma game

	Second Prisoner	
First Prisoner	Not Confess	Confess
Not confess	(1,1)	(10,0)
Confess	(0,10)	(5,5)

In this game both prisoners have an incentive to confess, whatever the other does. In this game, rational decisions by each individual prisoner make both worse off. Even if communication between the individuals results in an agreement not to confess, both have an incentive to break the agreement so that they may be set free (Sen, 1967). Therefore, the non-cooperative solution or Nash equilibrium to the prisoners' dilemma is a Pareto-inferior equilibrium.

Suppose a community of *N* herders who must graze cattle on a common range of a fixed size. If each herder formulates their grazing decisions independently, the result is an *N*-person variation on the prisoners' dilemma. Each herder must choose to either limit the number of cattle grazed or continue to graze at a level that, while advantageous to the individual herder, ultimately results in exploitative overuse of the grazing resource. This means the individual farmer has an incentive to graze as many cattle until the rent from grazing resource utilization is dissipated[11].

The cost of grazing to each herder is a function of the grazing decisions of all *N* individuals. If all cooperate and limit on the number of cattle grazed, the common range is preserved and cattle remain healthy and hence crop productivity is maintained at a higher level. Yet independently each herder (even with communication) has an incentive to defect and graze heavily in the near-term, over-exploiting the range in the long-run. The incentive structure is such that it does not matter which strategy the others choose. If the others choose to limit on the number of cattle grazed, then the individual becomes a free-rider -giving rise to the free-rider problem. The main features of this paradox are therefore:

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[11] Mathematically,

Let $f(x)$ be the value of cattle output produced if there were z cattle grazed under open access. Current output per animal is therefore $f(x)/z$. When an individual contemplates adding, say, an ox, total output becomes $(f(x+1)$ and the number of cattle $(z+1)$. Revenue generated by one ox for the individual is $f(x+1)/(z+1)$ = AP (average product). The individual farmer then compares this revenue with the marginal cost (MC) of keeping cattle. If $f(x+1)/(z+1) >$ MC, it is profitable to add an ox to one's herd since the value of output exceeds the cost. Hence the herder has an incentive to graze as many cattle until profit is zero.

a. Pareto-inferior outcome leading to resource degradation. Each individual will choose independently to graze at an exploitative level, leading to a situation in which all are made worse off. All are led toward a non-cooperative equilibrium.
b. Strict dominance of the individual strategy. The result of overgrazing arises independently of the expectations of each individual regarding the actions of others. Because the choices of each are logically independent, there is no problem of uncertainty about the actions of others.
c. Need for enforcement. Even if an agreement is struck that specifies all will limit on the number of cattle to graze on the range, the strict dominance of individual strategy makes such an agreement unstable. Without compulsory enforcement imposed by an outside authority, any such agreement is unstable because each prefers that others limit on the number of cattle grazed while they defect and graze exploitatively (Sen, 1967; Runge, 1981).

To mitigate the undesired effects of an open access regime due to independent choice, this study proposes that a possible option is to institute TGR as a grazing resource management strategy. This requires the government to formulate and enforce (or assist in formulating and enforcing) new rights that govern grazing resource management.

3.4 Inter-temporal preferences

In decisions that involve time, economic agents are observed to generally exhibit a preference for present consumption over future consumption of an equal amount of a resource (Kundhlande, 2000; IFAD, 1995). This means that when making inter-temporal decisions, consumers discount future utility. The uncertainty associated with the realization of consumption in the future is cited in the literature as one of the reasons why individuals may discount future consumption (Fisher, 1981; Randall, 1981; Tietenberg, 1991). Individuals have also been observed to discount future consumption even when it is perfectly certain to occur simply because they prefer current consumption more. The rate at which rational individuals, acting under certainty, discount future utility is called the pure rate of time preference (RTP). Preference for present consumption over future consumption resolves itself into preference for present income over future income (Fisher, 1981), and as a result discounting costs and benefits plays a crucial role in the evaluation of activities whose outcome involve a temporal dimension.

Most farm decisions involve some element of choice between present and future income. Farmers implicitly assess future costs and benefits, unlike those evaluating large projects for funding purposes (e.g. banks, government departments, the World Bank, etc.) who do it more explicitly. The implicit rates of time preference that farmers use are often not known, and are difficult to assess. However, given that many decisions with a bearing on the success of rural development policies depend to a considerable extent on the discount rates used by farm households, there is need for research to provide estimates of the magnitude and the determinants of farmers' discount rates.

Rates of time preference reflect a number of factors. Research findings suggest that there is no single unique rate in any setting (Thaler, 1981; Cropper et. al, 1991; Luckert and Adamowicz, 1993). An individual's discount rate is a function of his/ her life-cycle position, income, and other factors. Furthermore, different types of goods may be discounted using different rates; and the length of the time period a person has to wait to realize the future outcome may also influence the discount rate. This study seeks to provide some indications of the implicit discount rates used by farmers in grazing resource allocation over time.

There are a number of factors that affect the magnitude of the discount rate (Zilberman et. al., 1993):

i. The ability to use some resources today to produce a higher level of possible consumption in the future could be enhanced through technological progress. A higher indifference curve could be reached, and the equilibrium interest could be higher. This is because producers would be willing and able to pay a higher rate of compensation for the use of the foregone current consumption.

ii. Another important factor is risk. With uncertainty about the future period, individual herders may be more reluctant, and require higher compensation, to forego consumption today. Specifically, in the future period they may not be sure that they will receive the higher consumption possibilities of future time periods. The unsure they are, the more they have to be compensated.

iii. The third factor is the underlying rate of time preference. If a group of herders place more value on future grazing consumption possibilities, their preferences will reflect consideration for the possibilities available for future generations.

A herder has a positive time preference or a high marginal time preference rate (MTPR), if they prefer to consume immediately, rather than in subsequent periods, i.e., they would sacrifice a relatively high amount of a good to be consumed in the future in exchange for a small increment in current consumption. A herder has a negative time preference or a low MTPR if they will transfer part of their consumption in the current period to the subsequent one. A herder has a neutral time preference if they are indifferent between consuming resources today and deferring consumption into the future. This study will assess the herders' implicit time preference in grazing resource use.

The important implication of grazing time preference is that if the pervasive idea of high discount rates in grazing resource utilization leads to overgrazing, policy makers should look for ways to alter the behavior of households. Several options for eliciting the desired behavioural changes may be considered, including the establishment of credit markets and insurance schemes, and providing rural households opportunities to diversify risk in their production activities (Kundhlande, 2000).

3.5 Applications of Tradable Emission Rights

Based on a review of literature addressing pollution control and waste management, there are few in-depth evaluations of the application of regulatory and economic instruments in developing countries. Most reports provide information on the existence of standards or other regulatory or economic instruments and highlight the inadequacy of existing institutions and personnel to carry out effective monitoring and enforcement activities. There are no studies that focus on the application of tradable permits to grazing resource use. As a result the literature mainly available is that on air pollution control (Bernstein, 1993, Pearce et al., 1989; Bertram, 1992; Pezzey, 1988; Tietenberg, 1994; Simonis, 1994). Other studies that are reviewed focus on surface water pollution, ground-water protection, land use controls and solid waste management.

Marketable discharge permits have not produced impressive results in water pollution control. In the United States, for example, the state of Wisconsin implemented a program to control Biochemical Oxygen Demand (BOD) into the Fox River. The inflexibility of the program allowed only limited trading of marketable discharge permits. Firms were issued five-year permits that defined their waste load allocation, which in turn defined the initial distribution of permits for each firm. Although early studies indicated several potentially profitable trades involving large cost savings (on the order of US$ 7 million), since the program started in 1981, there had been only one trade by 1993 and actual cost savings were minimal (Hahn, 1989). Stringent restrictions on trades have significantly inhibited trading under this program (Oates, 1988). Numerous administrative requirements also add to the cost of trading and lower the incentive for firms to participate. Some costs are attributable to the small number of firms involved and others on the absence of brokering or banking functions (Anderson et al., 1989).

In the United States, the Environmental Protection Agency (EPA) Emissions Trading Program allows stationary air pollution sources to undertake internal and external trades to introduce more flexibility in the manner in which the objectives of the Clean Air Act are achieved. Under this program, any source that reduces emissions more than is required by the standard can apply to the control authority for an emission reduction credit (ERC). The ERC, defined in terms of a specific amount of a particular pollutant, can be used to satisfy emission standards at other discharge points controlled by the same source or can be sold to other sources. The ERC is the currency used in emissions trading (Tietenberg, 1991; Tietenberg, 1990). The ERCs may be applied internally through netting, bubbling, or offsetting. They may also be banked for future use or sale.

According to Oates (1988), the results of the Emissions Trading Program have been mixed. Although the program substantially increased the flexibility with which sources can meet their discharge limitations, most of the trades have been internal. This is due largely to the extensive and complicated procedures required for external trades, and their related high costs, along with uncertainties about the nature of the property rights being acquired. Nonetheless, the costs of complying with Clean Air Act requirements under the Emissions Trading Program have been substantially reduced. Most estimates place the accumulated capital savings at over US$12 billion. Although the cost savings have been substantial, the program has led to little or no net change in the level of emissions (Hahn, 1989).

One program in the United States that has produced an active trading market is the "inter-refinery" program for lead rights. Under this program, refineries have actively traded the right to add specified quantities of lead to gasoline. During the first half of 1987, for example, around 50 percent of all lead added to gasoline was obtained through trades of lead rights with large cost savings reported. The reason for the program's success may be that the market on lead rights has relatively few restrictions and administrative requirements to inhibit trading (Oates, 1988). Other reasons given for its success are that the amount of lead in gasoline is easily monitored and that the program was implemented after a consensus had been reached that lead was to be phased out of gasoline (Hahn, 1989). Due to these reasons, the success of the lead trading program may not be repeated in other applications where monitoring is problematic or where environmental goals are poorly defined (Hamrin, 1990).

Since 1990, additional applications of emission trading were introduced. With respect to sulphur dioxide emissions from utility plants, which contribute to acid rain, the Clean Air Act Amendments of 1990 established a comprehensive permit and emission allowance system for U.S. facilities. Facilities receive allowances based on specific formulas contained in the law. These allowances may be traded or banked for future use or sale. If an affected unit does not have sufficient allowances to cover its emissions, it is subject to an excess emission penalty of US$2 000 per ton and required to reduce an additional ton of pollutant the next year for each ton of excess pollutant emitted (Parker, 1991).

Though there are not many examples of countries where tradable rights or permits have been used, the above shows that the use of tradable permits may be successfully used in environmental quality management depending on the complexity of administrative issues that have to be tackled. An important factor in the success of using TGR seems to be the low cost monitoring and enforcement. Hence this study proposes to adapt the work on pollution control to grazing resource management in the communal areas using TGR.

3.6 Linear Programming and Bio-economic Model in Renewable Resource Management

To assess the cost-effectiveness and equity impacts of TGR, this thesis will use a recursive bio-economic linear programming model. This section therefore reviews the use of linear programming (LP) and bio-economic models in natural resources management. In the literature the optimization models that can be used are generally classified into static and dynamic models. For dynamic models, optimal control has become the standard approach to studying renewable resources at the microeconomic level (Cacho, 2000). This trend was partially fuelled by fisheries economists in the 1960's, who used a simple growth model of a fish population to develop the theory of optimal exploitation under both open access and private property. Optimal control is well suited to these problems because of the long-term and dynamic nature of natural resource problems. The technique also provides important information in terms of dynamic shadow prices.

Analytical solutions of optimal control models for resources such as fish, soil and forests are well documented (Kaimowitz and Angelsen, 1998; Carlson et. al., 1993; Conrad and Clark, 1987). These models are generally based on the logistic equation or a similar function that can be manipulated to perform policy analyses. An extension of this work has been the use of biophysical simulation models to mimic the dynamic behaviour of the resource of interest. In practice, most applied optimal control problems are solved as either nonlinear programming or dynamic programming models. These techniques can handle a variety of difficult problems and are not restricted to continuous and differentiable functions, but they have important limitations as in the problems of dimensionality and convergence to local maxima (or minima) (Cacho, 2000). The solution of optimal control models, however, is not trivial. Analytical solutions are only possible with very simple models and direct numerical solutions are plagued with difficulties.

In its simplest form Linear Programming (LP) is a method of optimizing a linear objective function subject to simultaneous consideration of multiple inputs and outputs subject to constraints (Kehmeier, et. al., 1987; Hazell and Norton, 1986). Any LP analysis starts by defining the decision variables, which are different alternatives stated by the problem. After defining the decision variables the objective function is defined subject to constraints. Each constraint is formulated as a linear equation whose, right hand side constant represent, the limit of the available resources. To solve any linear programming problem the objective function and all the constraints must be strictly linear over the domain of each activity. In this technique each linear variable can assume any real value including both real and integers and fractions. All right hand side values are assumed to be known constants. All activities must be at least equal to zero, that is negative assignment should not be included in the model (Hazell and Norton, 1986). LP makes it possible to obtain the optimal solution of the problem in order to make the objective function maximum or minimum while at the same time fulfilling all the requirements set by the constraints. Linear programming is able to give a synthetic approach to complex situations.

At each optimal solution there is a dual variable which is interpreted in economics as the shadow price. This shadow price is the LP's internal barter price for inputs in terms of the objective function revenues (Kehmeier, et. al., 1987). If the price of the i^{th} factor exceeds the marginal value imputed to the i^{th} variable in the j^{th} activity, the factor will not be utilized by the j^{th} activity. This is analogous to the equal-marginal rule which stipulates that factors are utilized up to the value of their marginal product (Hazell and Norton, 1986: 16).

Linear programming is severely limited because biological responses are seldom linear. Further, the analyses are usually confined to 'average' or specific seasons, whereas it is often the economic consequences of a variable sequence of seasons that determines optimal farming strategies (Barbier and Bergeron, 2001). Despite these limitations, it is possible to transform non-linear functions into linear functions and use them in LP and this provide insights into policy decision making at times even more than when non-linear functions are used (Hazell and Norton, 1986).

3.6.1 Application of LP models

Linear programming (LP) has been used since the 1950s in a wide variety of planning situations (Dantzig 1983). Its application field ranges from business planning management to the problem of spatial organization. In agriculture, LP has wide application to the analysis of substitution (Barbier and Bergeron, 2001). For example it is commonly used in the formulation of least-cost livestock rations in which the desired content of energy, protein, minerals and vitamins can be made up from within a wide range of alternative ingredients of differing composition and price. It can also be applied to problems of pasture-crop rotations in mixed farming systems (Kehmeier, et. al., 1987). It has also been used to analyze the profitability of alternative cropping options with constraints in land but in their various combinations introduce complex interrelationships in the management of water and nitrogen and in the control of weeds and diseases. The objective of the producer is usually to maximize profitability in the face of changing costs of inputs and prices for products. Where LP has been used to address issues in ranching or grazing operations includes empirical investigations of range degradation resulting from the effect of considering the impact of current stocking decisions on future range conditions (e.g. Torell et. al., 1991, Pope and McBryde, 1984).

Several linear programming models for simulating land degradation have recently been developed, including variables such as soil erosion (Barbier, 1998) and soil nutrient or organic matter depletion (Parikh, 1991; Kruseman et. al. 1995; Barbier, 1998). Specific to Zimbabwe, Stocking (1972, 1978) Stocking and Elwell (1973) and Whitlow (1988) did extensive work on rainfall, land degradation and soil erosion in the communal areas. However, none of these models provides specific links between rangelands degradation due to overstocking, livestock productivity and the resulting crop productivity and in turn how crop productivity impacts on cattle productivity.

3.6.2 Bio-economic models

From a management standpoint, populations of natural organisms, such as fish or forests, are best viewed as stocks of capital assets that provide a flow of services. Furthermore, it may be convenient to account for interrelationships among populations that make up the "portfolio" of natural resources (Wilen, 1985). Hence a bio-economic approach to the management of natural resources is required.

The term *bio-economics* means different things to different people. From a macroeconomic standpoint, the term has been used to describe the need to account for energy use and the laws of thermodynamics in models of economic growth (Cleveland, 1987). The neoclassical economic model is incomplete because it ignores the physical interdependence of capital, labor and natural resources (Cacho, 2000). At the microeconomic level, Van der Ploeg et al. (1987) defines bio-economics as economic research based on the application of optimal control theory in the context of models of the population dynamics of exploited species. To Allen et al. (1984) bio-economics refers to the use of mathematical models to relate the biological performance of a production system to its economic and technical constraints. Thus, generally speaking, a bio-economic model consists of a biological (or biophysical) model that describes the behavior of a living system, and an economic model that relates the biological system to market prices and resource and institutional constraints. The latter definition is adopted for this study.

3.6.3 Applications of bio-economic models

Fisheries economists such as Clark (1976, 1985), and Clark and Munro (1975), have made important contributions to the development of bio-economic approaches to natural resource management. Clark and Munro (1975) call attention to the importance of explicitly accounting for time in fishery economic models. They present an introductory treatment of optimal control theory. Clark (1976, 1985) has been influential in stimulating the application of optimal control and capital theoretical concepts to fishery management problems. Conrad and Clark (1987) present an amenable treatment of optimal control applied to natural resources. These studies deal with simple mathematical population models, which are solved analytically and provide good insights into the nature of dynamic optimization.

Biophysical models developed by economists to represent renewable resources tend to be too simple by biologists' standards – see, e.g., Huffaker and Wilen (1991), LaFrance (1992), Goetz (1997) and Hu et al. (1997). However, many of the variables and parameters included in complex simulation models may be of little relevance from a decision-making standpoint (i.e., the optimal decision rules are not sensitive to the values of these model components). Commonsense, experience and sensitivity analysis on large models has been used to identify those variables to be excluded from the model to eventually reach a compromise between simplicity and realism which is mutually acceptable to economists and biologists.

The literature on suitable models for simulating integrated crop–livestock systems is growing (Kehmeier, et al., 1987). The models include biophysical components for simulating the productivity of pasture areas, and the status and yield consequences of soil-nutrient balances and the amount of organic matter in the soil. Until recently, most models were designed at the farm level. However, given the prevalence of common and open-access land, new village- and community-level models have been developed to explicitly include these lands (Kebe, 1992; Barbier and Benoît-Cattin, 1997). Natural resource management usually includes problems that go beyond village specific boundaries due to the open access use of the resources. This feature has been included in community-level models developed by Taylor and Adelman (1997); Barbier and Benoît-Cattin (1997). Also given the importance of climate and price variability, several models have incorporated risk (production variance) and risk averse behavior using such methods as MOTAD (Hazell, 1971); Target MOTAD (Tauer, 1983); Focus-Loss constrained programming (Boussard and Petit, 1967); and discrete stochastic programming (Cocks, 1968; Rae 1970, 1971).

Torell et. al. (1991) determined 40 year optimal biomass time paths associated with both single-period and dynamic models. In both models, grazing pressure directly impacts current period beef production. Their results indicate little differences from using short-run planning horizons as opposed to considering the long-run impacts of overstocking. However, Pope and

McBryde (1984), argue that degradation of the range may occur in the long-run when using short-run planning horizons for stocking decisions in cow-calf operations.

For purposes of this study, to quantitatively estimate the potential economic effects of adopting tradable grazing rights (TGR) versus the status quo, a simplified bio-economic linear programming model is developed. The bio-economic linear programming model developed simulates the effects of TGR given the levels of rainfall, stocking rates, and farmers' budget constraints on household income, household food security and grazing pressure. Following the methodology used by Torell et. al., (1991), the model developed is for a five-year planning horizon, i.e. a recursive model. In its most general form a recursive model is a sequence of optimization problems in which one or more parameters or coefficients in the problem in the sequence are functionally dependent on the optimal variables of preceding members of the sequence (Hazell and Norton, 1986). For this study, a sequence of comparative static solutions in each time period will be based on the optimal solution for the previous period.

3.7 Summary

This Chapter presented the literature review for the study. The issues covered were on the public nature of grazing resources, a distinction of open access and common property resources, and theoretical explanations of the overgrazing problem. A review of the role of time preference in inter-temporal resource allocation was presented.

A review was made of the evolving field of optimization modeling using bio-economic LP models to resolve decision making problems in natural resources management. These models can be static or dynamic and the decision of which to use is dependent on the objective of the analysis. For purposes of empirically testing the efficiency of using TGR for grazing resource management, this study will adopt the use of recursive LP modeling.

CHAPTER IV: ADAPTATION OF POLLUTION ABATEMENT CONTROL THEORY TO GRAZING: AN ANALYTICAL FRAMEWORK

4.0 INTRODUCTION

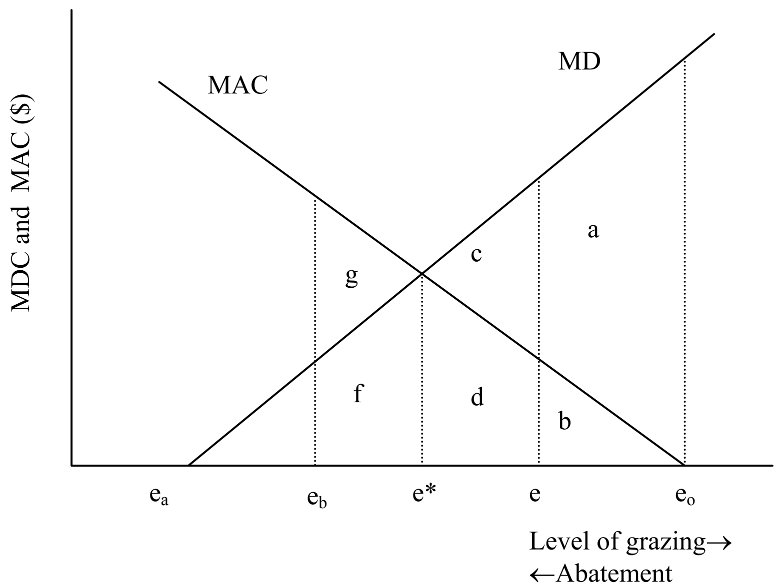
This chapter presents the theoretical framework of the study based on an adaptation of work on fisheries resources management and pollution control. This is so because literature on the application of tradable grazing rights to grazing resources control is scarce. The theory of optimal grazing, including global and local grazing optima, is discussed in Sections 4.1 and 4.2 respectively. Then a comparative analysis of the cost-effectiveness of tradable rights/permits, taxes and standards is made in Section 4.3. The comparative analysis aims at testing the hypothesis that tradable rights are more cost-effective, equitable, and dynamically efficient than taxes and standards. Issues of monitoring and enforcement costs of grazing resource management policies are presented in Section 4.4.

4.1 Optimal Level of Grazing

Before the alternative policy instruments for grazing resource use can be discussed, there is need to discuss the concept of optimal stocking rates using a framework used in pollution control analysis. The framework adapted here makes a comparative analysis of the alternative policies much easier. From Figure 4.1, it is possible to envisage that the pasture is able to assimilate level of physical damage due to grazing animals, e_a, without permanent harm to the pasture (Bright and Latacz-Lohman, 1998; Field, 1994; Pezzy, 1988; Nichols, 1984). The question we need to answer is, from an economic point of view, should grazing be eliminated? That is, should the government force herders to reduce their cattle numbers to zero? From Figure 4.1 it is clear that some level of grazing can be assimilated by the rangeland without causing permanent damage. So should the government force herders to reduce grazing levels to e_a? Herders incur a cost for every unit of damage reduction, the marginal abatement costs (MAC), which, for simplicity, is assumed to be linearly increasing with damage abatement. Abatement, in the case of grazing control could take a number of forms:

- Reducing the number of animals grazing on the pasture,
- Augmenting the pasture biomass productivity by planting legumes, and

➢ Contributing labor time to rehabilitating degraded grazing land.



e_a is the level of pasture degradation that can be assimilated by the environment without causing permanent damage.

e_o is the initial level of grazing (i.e. number of cattle on the veld).

Source: Adapted from Bright and Latacz-Lohman,1998; Pezzy, 1988; Field, 1994

Figure 4.1: Marginal damage to pasture due to overgrazing

The area under the marginal abatement cost curve is the total abatement cost, and the area under the marginal damage curve is the total damage. Mathematically:

$$TD = \int MD$$

$$TAC = \int MAC$$

Similarly,

$$MD = \partial\, TD / \partial\, e$$

$$MAC = \partial TAC / \partial e$$

Now suppose the level of grazing is reduced from e_o to e:

- Total benefit gained in terms of reduced damage to the pasture = area **a** + **b**
- Total cost of abatement = area **b**

There is thus an increase in welfare equal to area **a** in reducing the level of grazing activity from e_o to e. Similarly, there is an increase in welfare for reducing the level of grazing activity from e to e*.

Should the level of grazing be reduced even further? What are the extra costs and benefits if the level of grazing is reduced to e_b, a point between e_a and e*?

- Extra abatement costs = **g** + **f**
- Extra benefits in terms of reduced damage = **f**

It is therefore not beneficial to the community to reduce the level of grazing further than e*, as the costs outweigh the benefits. Hence, e* is the optimal level of grazing and it occurs where the marginal abatement cost = marginal damage cost. The optimum can only be achieved by the market mechanism. Government intervention may not be able to determine e* since it is dynamic and responds to both changes in the environment and the micro and macro economy. Government policy can, however, support institutions that will enhance a more equitable and more efficient market outcome.

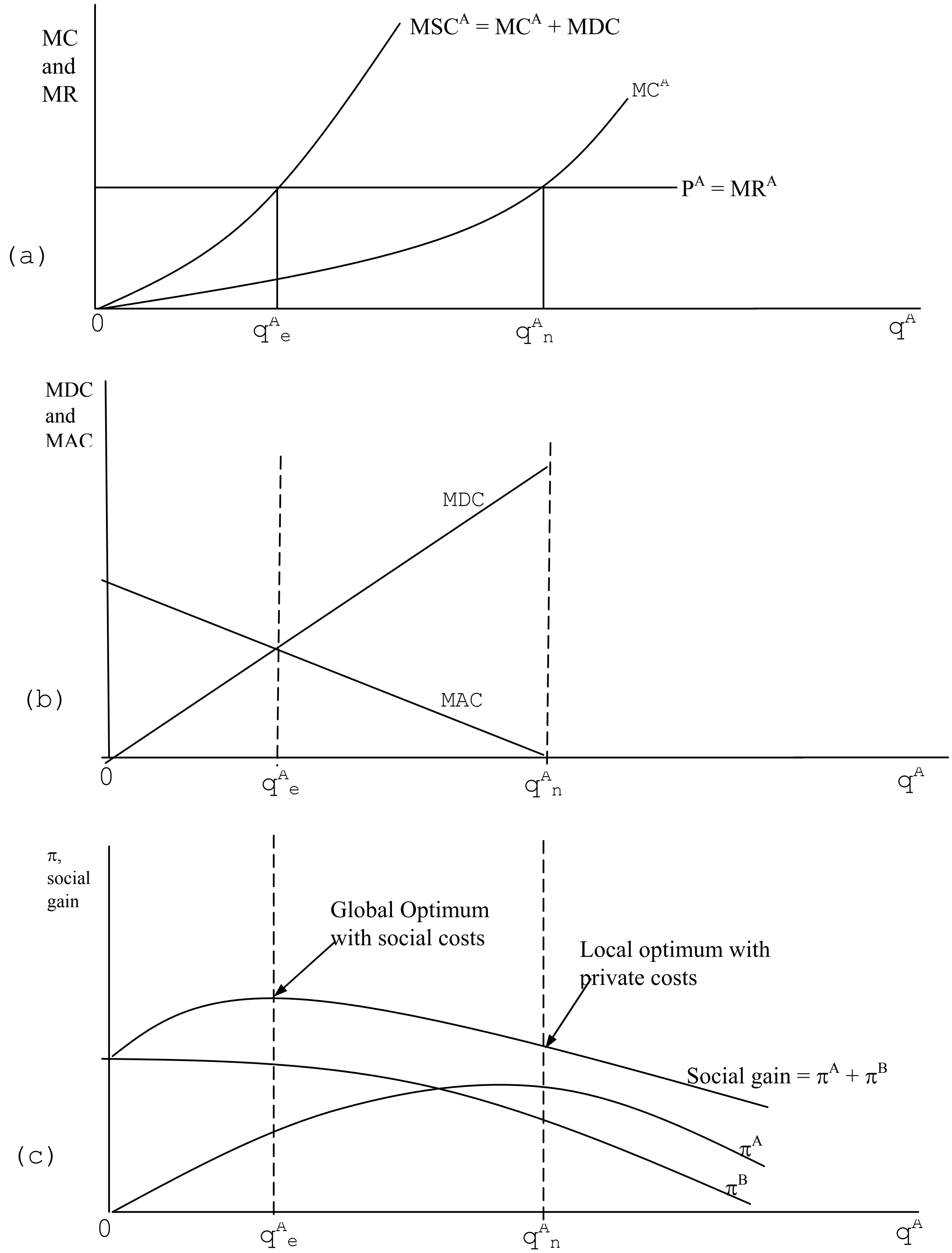
4.2 Global and Local Optima in Grazing Resource Use

The problem of overgrazing is treated as an externality cost in production. Such costs occur because the herders disregard them when they arise and there is no legal obligation to take them into account (Burrows, 1995; Neher, 1990). The absence of a legal obligation means the herders have no externally imposed incentive, financial or otherwise, to balance the benefits of grazing against the harm caused to other herders that the external cost represents, in deciding on the number of cattle to keep (Burrows, 1995). If such an incentive were introduced, it would effect the internalizing of the external costs. Thus, the external costs would be part of the herder's decision calculus.

An illustration of the effect of external costs in grazing and the effects of internalizing the costs is presented in Figure 4.2. For the interpretation of the figure, let's assume the case of overgrazing which has the following characteristics:

a. There are only two herders, A and B. Herder A has a large cattle herd which damages the pasture and hence affects the cattle production of herder B who has a small herd,
b. The herding external costs are imposed unilaterally, i.e. herder A's cattle production activity negatively impacts on herder B's activity[12],
c. Both herders are profit maximizers,
d. The herders can reduce rangeland damage (r^A) by reducing on the number of cattle grazed (q^A),
e. Total external cost is a positive strictly convex function of the level of grazing, and therefore the level of herder A's output. Thus the marginal damage cost increases with an increase in herder A's cattle (Figure 4.2b). With each unit increase in herder A's cattle, herder B suffers increasing losses in productivity,
f. Total abatement cost is a positive convex function of the level of rangeland damage abatement i.e. it is a negative convex function of the level of grazing up to some grazing level where total abatement cost is zero. This means starting from a position of zero abatement, from herder A's profit maximizing output $q^A{}_n$ in Figures 4.2a and 4.2b, the marginal cost of abating rangeland damage rises with each unit decrease in herder A's number of cattle. Therefore the rising marginal abatement cost curve is viewed from right to left in Figure 4.2b. This seems to be a reasonable assumption as in general, it will be more expensive to reduce the pasture damage by one more unit when the degradation has already been controlled, than at the start of the grazing rehabilitation program.

[12] This is a strong assumption which is used to merely simplify the analysis. In a more complete model, it is better to recognise the interdependence of the output choices of the two herders (Burrows, 1979).



Source: Adapted from Burrows, 1995

Figure 4.2: Global and local optima in external cost theory of grazing

If herder A ignores the external cost, they will produce at output level q^A_n where marginal private cost equals marginal revenue, $MC^A = MR^A$ in Figure 4.2a. This minimizes abatement costs at zero in Figure 4.2b and maximizes profit for herder A, π^A, in Figure 4.2c.

The profit level of the damage victim is shown by π^B in Figure 4.2c. Now, let herder A abate rangeland damage by reducing on the number of cattle from q^A_n to q^A_e. Also let the sum of profits by both herders be $\pi^A + \pi^B$, the social gain from the two activities together. Increasing herder A's output from $q^A = 0$ to q^A_e raises the social gain because the marginal damage cost is less than the marginal abatement cost (MAC > MDC from 0 to q^A_e in Figure 4.2b). Further increases in q^A above q^A_e reduce the social gain because for each of these unit increases in the number of cattle grazed, the damage cost created exceeds the abatement cost avoided (MAC < MDC at outputs above q^A_e in Figure 4.2b). So herder A's output level q^A_e is socially efficient.

The maximization of the social gain from the outputs of herder A and herder B can be achieved if herder A is compelled to bear the full marginal social cost of production ($MSC^A = MC^A + MDC$). Herder A will then choose output level q^A_e because this maximizes profit net of damage costs. The output level is characterized by $P^A = MSC^A$. By implication, MAC = MDC when $P^A = MSC^A$.

4.3 Policy Instruments for Sustainable Grazing Resource Management

This section provides a comparative analysis of the different policies that can be used for grazing control. Market achievement occurs when the self-interest of individual herders (i.e. market-like forces) can be used to achieve optimal grazing control without the need for major government intervention. Bargaining between owners with large herds of cattle and those with small herds (so as to reduce degradation) is one example. This process occurs by the application of the Coase Theorem (Pearce and Turner, 1990; Carlson et. al., 1993).

4.3.1 Criteria for evaluating environmental policies

Now that the basic framework of analysis is developed, the next step is to define the criteria for evaluating environmental policies – in this case policy for grazing resource management in the communal areas. The four main criteria for evaluating environmental or natural resource policies are (Bohm and Russel, 1999; Bressers, 1999; Nichols, 1984):

- Cost effectiveness and economic efficiency,
- Fairness or equity,
- Dynamic efficiency, and
- Enforceability.

4.3.1.1 Cost-effectiveness

Cost-effectiveness, in general terms, refers to the concept of either maximizing outcomes with given resources or achieving a given outcome with minimum resources. An efficient policy is one that results in marginal abatement costs equal to marginal damages (benefits). It is not always possible to achieve an efficient policy because damages due to environmental degradation are often impossible to measure. An efficient policy is always cost effective but a cost-effective policy is not necessarily efficient, as marginal costs might not be equal to marginal benefits. The best policy would be economically efficient, that is, one that would strike a balance between environmental benefits and abatement costs at the point where MDC = MAC. However, this is not an easy task as the exact locations of the MAC and especially of the MDC curve are not normally known. In such cases, we settle for a cost-effective policy. That is one that either:

- Given the resources, yields the maximum environmental improvement possible,

or

- Yields a set amount of environmental improvement for the lowest cost.

Note that there are two different concepts of cost-effectiveness; one based on economic (or social) costs, and one based on public costs. This discussion focuses on the economic costs, which comprise:

- Opportunity costs,

- Costs of administration and control, and
- Pre-policy costs involved in the negotiation of a social agreement.

The last two cost components are sometimes referred to as transaction costs. However, the pre-policy negotiation costs, not being amenable to quantification, are normally not considered in cost-effectiveness analyses.

The second cost-effectiveness concept refers to the cost-effectiveness of public spending. It comes to bear when the policy instrument is a subsidy. The government will want to 'buy' the maximum environmental benefits within a given budget. Subsidy payments are not considered an economic cost (resource cost), but just a transfer of funds from one party to another, and therefore does not count in an economic analysis except when assessing benefits distribution.

4.3.1.2 Fairness or equity

Besides basing judgment of environmental policies on cost-effectiveness and economic efficiency, it is also important to consider the distributional impacts of the policy and how it affects different constituents. Fairness or equity considerations play a much greater role in the political decision-making process than cost-effectiveness or economic efficiency. Interest groups that will be affected by the introduction of an environmental policy include:

- Herders who have to alter their behavior, and possibly their customers if they face a change in product price,
- Non-herders who may not be currently benefiting from grazing resource use and who may be paying the costs of degradation i.e. reduced access to edible insects and fruits, mushrooms, medicinal plants, thatching grass etc. These may benefit if, for example, tradable grazing rights are introduced, and
- Future generations who may be affected by present grazing resource damage.

4.3.1.3 Dynamic efficiency

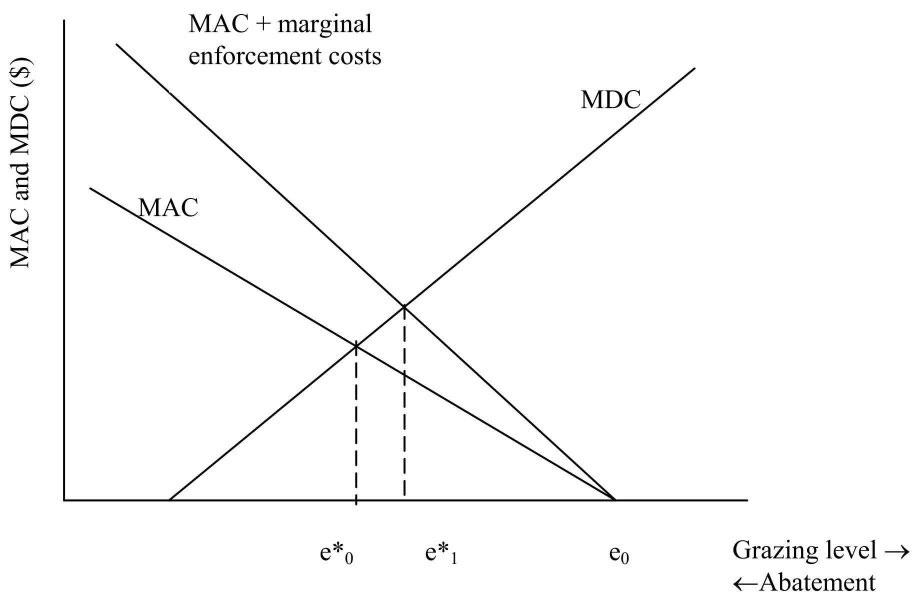
The dynamic efficiency criterion is concerned with whether the policy provides incentives for herders to improve their abatement efficiency over time. Clearly, a policy, which encourages herders to invest in new and improved abatement technology or to implement less environmentally damaging grazing practices, is to be preferred to one that offers no such encouragement. Innovation is important because it can increase the efficiency in the use of the range. In other words, society can afford higher levels of environmental quality. The ability for a system to be flexible and change in response to changing demand and supply as a result of technology, education and population growth is the foundation of successful economic growth.

Dynamic efficiency in grazing control can result when farmers start practicing zero grazing. This can be achieved by producing fodder for the cattle or if farmers start supplementing their cattle feed requirements with feed concentrates. Thus, cattle are taken off the veld, resulting in an improvement in the quality of grazing resources.

4.3.1.4 Enforceability

There is no point in introducing a new environmental policy if it is not easy to enforce. Especially for complex environmental schemes, it may be very difficult, and hence costly, for the regulatory body to observe whether herders are keeping to the policy. Enforcement costs must be taken into account in any overall assessment of environmental policies. High enforcement costs increase the optimal grazing level and reduce environmental quality (Figure 4.3).

Figure 4.3: Effect of high enforcement costs on optimal grazing level



e^*_0 optimal grazing level with no enforcement costs
e^*_1 optimal grazing level with enforcement costs

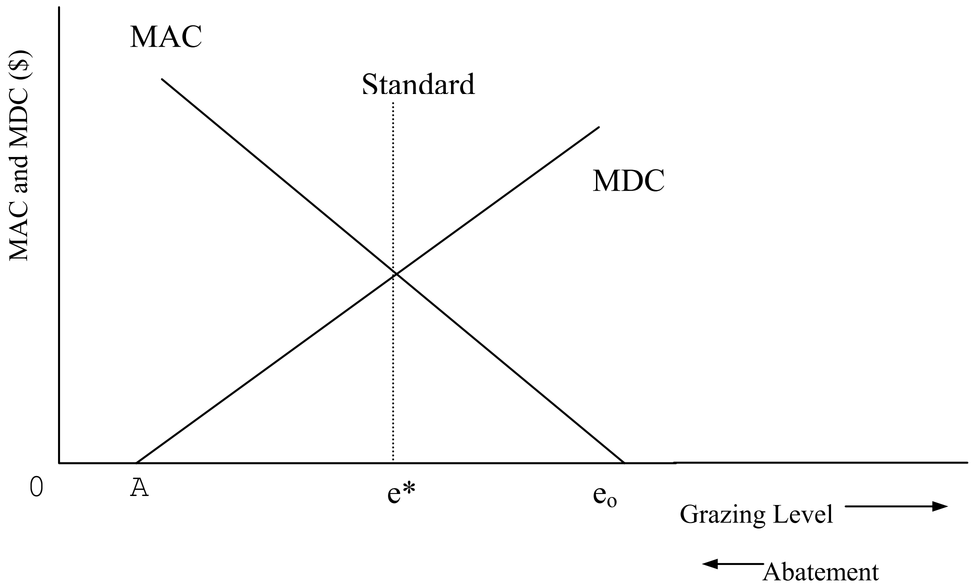
Source: Adapted from Bright and Latacz-Lohmann, 1998; Pezzy, 1988

4.3.2 A comparative analysis of the cost-effectiveness of standards, taxes and tradable permits

4.3.2.1 Standards

The command-and-control approach is the most commonly used approach in environmental policy. The government or regulatory body decides on the level of the standard, i.e. the grazing level that is allowed on a pasture of a given quality, given rainfall levels. The number of grazing animals is taken as the target of policy. It is assumed that the government will want to set the standard at the optimal level of grazing, that is, at the point where MAC = MDC. The optimal grazing level with a standard is at point e^* in Figure 4.4. This was the solution chosen by the settler government in the 1950s when massive de-stocking and cattle numbers were controlled in the former Tribal Trust Lands (the now communal areas).

Figure 4.4: Optimal grazing level of a standard



Source: Adapted from Bright and Latacz-Lohmann, 1998; Nichols, 1984

However, a policy based on standards is highly unlikely to be economically efficient, i.e. hit the optimal level of grazing, e^*, because of informational deficiencies and the fact that grazing control costs differ between individual herders. The obvious question then is whether standards can achieve a given, predetermined (but not necessarily the economically optimal) reduction in the grazing level in a cost-effective manner.

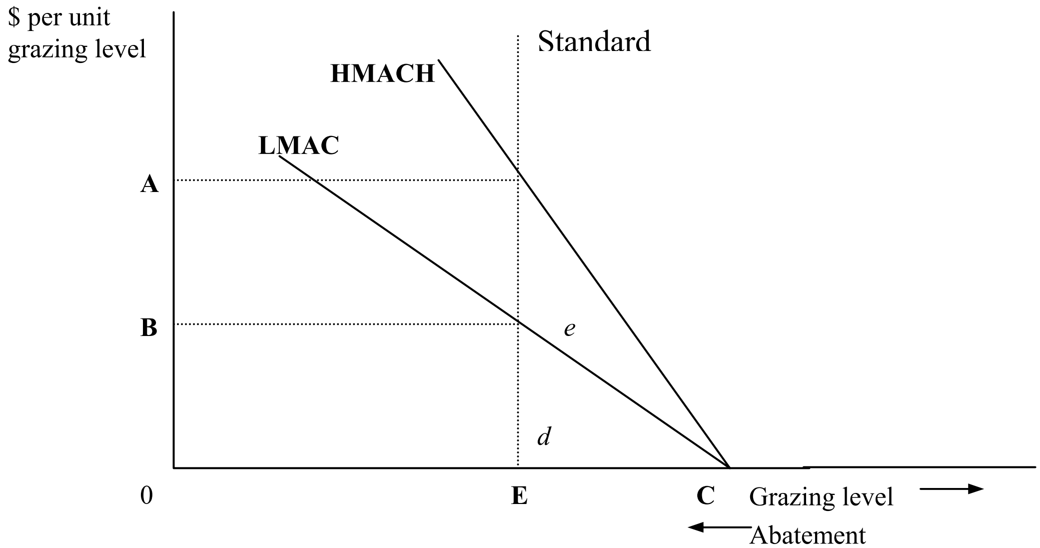
There are many reasons why herders may face different abatement costs: they may be using different production processes or abatement technologies. For example, for some households cattle are owned by several individuals hence they cannot be disposed of easily. Some cattle are bride price cattle, some cattle are for ceremonies and therefore disposing of them will be costly, hence high abatement costs. This household with high abatement costs will be denoted by HMACH. Compare this with a situation whereby one individual in the household owns all the cattle and has enough cattle for draft power, milk, manure etc. The individual can easily afford to supplement cattle off the veld and do not need to consult anyone to de-stock. This household has low abatement costs and will be denoted by LMACH.

Suppose the two types of herders have the same initial grazing level, C. Also, suppose the regulatory body now sets the standard for grazing level E. Both households/herders must obey the same standard E. Given this information, the cost-effectiveness of a standard is illustrated in Figure 4.5. LMACH incurs costs equal to area **d**, while HMACH incurs costs of **d + e**. Therefore, the total costs of meeting the standard by the herders are **2d** + **e**.

However, this is not a cost-effective outcome, because for the cost-effective outcome, the marginal abatement cost at the optimal level should be equal for the two herders. With the standard set at E, however, the marginal abatement cost for the high-cost herder is A, and for the low-cost herder it is B.

Now suppose HMACH would be allowed to graze one more livestock unit on the pasture (i.e. exceed the standard by one unit), while LMACH would abate one additional unit. Then the herders' grazing level would remain unchanged, but HMACH would save abatement costs equal to A, while LMACH would incur additional costs according to B. As A > B, there is a net cost saving. As this substitution continues, further cost savings can be realized up to the point where the marginal abatement costs are equal for the two herders. In other words, the condition for a cost-effective outcome is that, using the equi-marginal principle, marginal abatement costs are equalized across sources.

Figure 4.5: Cost-effectiveness property of a standard



Source: Adapted from Bright and Latacz-Lohmann, 1998; Field, 1994

Although it appears that the two herders are being treated fairly as they face the same standard, in fact herder HMACH incurs considerably higher costs than herder LMACH to meet the standard. Furthermore the standard can only be set if the government has the information to determine the standard.

4.3.2.2 Taxes

With a tax system, the tax is set in terms of $ per unit of grazing where MDC = MAC. The difference in depicting a tax and a standard should be noted (Figure 4.6). The standard, as a quantity-based instrument, is depicted as a vertical line on the quantity (grazing level) axis, while the tax, as a price instrument, is drawn as a horizontal line on the price axis.

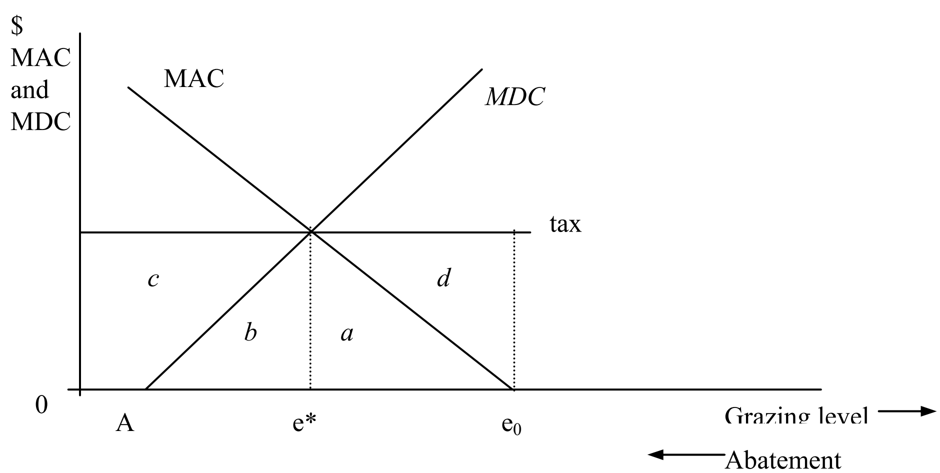
A tax set at the correct level encourages the herder to reduce the herd size to the optimal level e*. With a tax, there is no element of compulsion as with the standard. It is up to the herder whether and to what extent they respond to the tax. However, it is in the herder's self-interest to move to e*.

At e_0 (i.e. no response to the tax) total cost = **a** + **b** + **c** + **d** (tax)

At e*, total cost = **b** + **c** (tax) + **a** (abatement costs)

Savings from moving to e* = **d**

Figure 4.6: Optimal grazing level with a tax



Source: Adapted from Bright and Latacz-Lohmann, 1998; Pezzy, 1988

These savings provide the incentive to the herder to reduce grazing level from an initial level of e_0 to e*.

If the government can estimate the marginal damage and marginal abatement cost curves accurately, it can set the tax at the optimal level, but similarly to the case of a standard, it is unlikely to be able to do this because of information deficiencies. Even if it could estimate the initial level, bureaucracies are unable to respond timeously to changing circumstances.

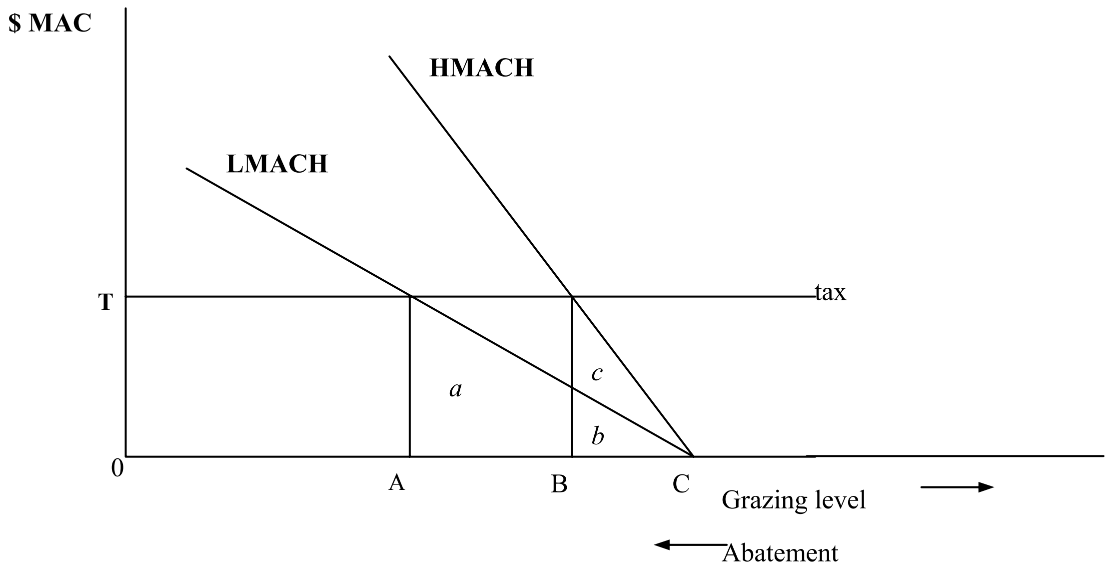
A comparison of Figures 4.4 and 4.6 demonstrates what is considered to be one of the disadvantages of a tax system: it creates a **double burden** for the herders: they must not only pay the abatement cost **a**, but also the tax **b** + **c** on the remaining grazing levels. The cost of the remaining grazing damage is **b**, so is it fair to charge the herder **c**?

To assess the cost-effectiveness of a tax, lets consider again the two herders with different abatement costs (LMACH and HMACH with low and high abatement costs, respectively). In Figure 4.7, T denotes the tax rate.

After the imposition of the tax, herder LMACH reduces grazing level to A, incurring an abatement cost of **a** + **b**, while herder HMACH reduces grazing level to B, incurring an abatement cost of **b** + **c**. Thus the two herders respond differently to the introduction of the tax, depending on the abatement cost functions they face. The figure clearly demonstrates that the marginal abatement costs at points A and B are equal for the two herders, namely LMACH = HMACH = T. In other words, the condition for cost-effectiveness is met, hence any given level of aggregate grazing reduction is achieved at lower cost under a tax than under a standard.

It should be noted that, in theory, the same cost-effective outcome could be achieved by setting two separate standards, namely at A and B. However, this would require the regulator to have sufficient information on both herders' MAC curves. With a tax, this information is not required. Instead, economic self-interest steers the herders to take the right actions. In fact, by choosing points A and B, both herders reveal a point of their MAC curves to the regulator.

Figure 4.7: Taxes and cost-effectiveness



Source: Adapted from Bright and Latacz-Lohmann, 1998; Field, 1994

4.3.2.3 Tradable grazing rights

The setting up of a permit system essentially involves four steps (Bright and Latacz-Lohmann, 1998; Anderson et. al., 1997; Simonis, 1994; Tietenberg, 1991; Lyon, 1982):

Step I: A political decision must be taken as to the acceptable overall grazing level in an area. This determines the total number of permits to be issued. The total number of permits issued will depend upon the goals of the environmental policy. Ideally, the total number of permits should correspond to the optimal level of grazing. However, as with other instruments, this would require perfect information about the biological and production relationships as well as the MD and MAC curves that is unlikely to be available. A tradable rights system at least allows individuals to optimize permits within the overall limit. Tradable rights also mean that the authorities can afford to initially underestimate overgrazing or overestimate the number of permits because they can latter buy back permits if there is the need to reduce pressure.

Step II: It must be decided how the permits are to be initially distributed among herders. One basis for initial distribution is the current grazing levels for herders. That is, herders receive a number of permits calculated *pro rata* on their existing grazing levels. This is known as grand-fathering. While this is not the only way to determine the initial allocation, the experience with emissions control in developed countries shows that grand-fathering tend to be the most acceptable formula for all parties. Clearly this will make entry by new herders more difficult as they receive no initial allocation of permits and they will need to buy permits from existing herders in order to graze their cattle. It would perhaps be more equitable to give all adult members of the community an equal number of grazing rights on a yearly basis or any pre-determined and agreed-upon time.

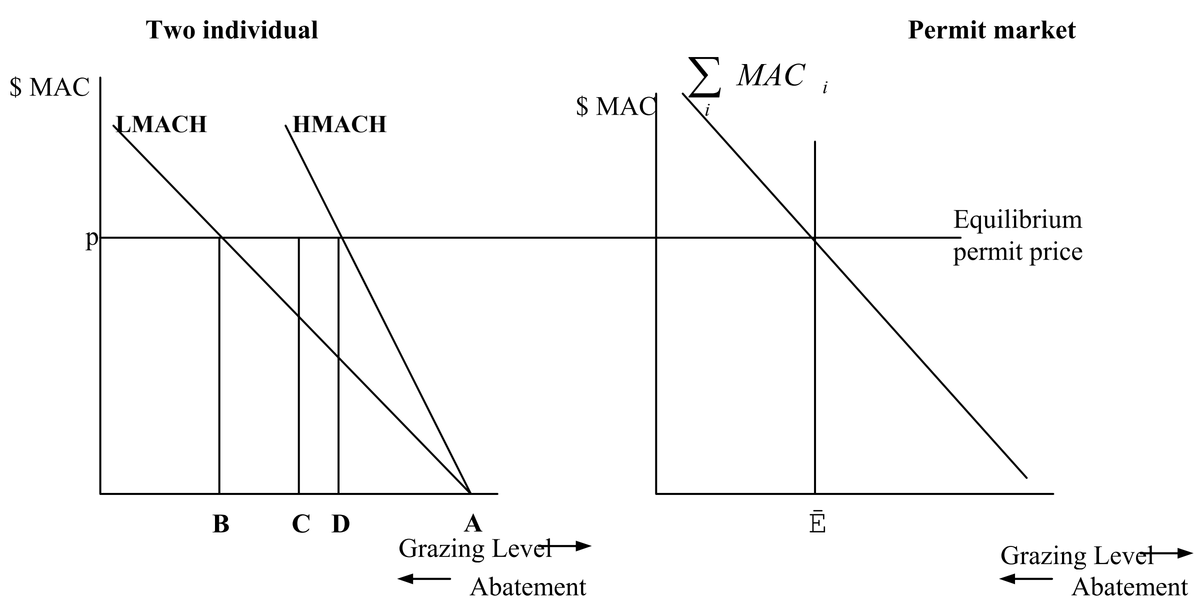
The initial permits could be given to community members free of charge, they could be sold at a fixed price or they could be auctioned. In the last two cases, herders must take the cost of the permits into account in their decision of how many to buy.

Step III: Once the permits have been distributed, a market must be created between herders. It is the tradability that accounts for the main attraction of a permit system. It is shown below that because of this characteristic, the permit system has the ability to keep down the overall cost of grazing reduction.

Step IV: Along with creating the permit market, methods of monitoring and sanctioning the herders in the market need to be established.

It has already been mentioned that the regulator is unlikely to have sufficient information to issue the socially optimal number of permits, i.e. the one that corresponds with the optimal level of grazing. As with other instruments, a permit system is unlikely therefore to be economically efficient. To illustrate the cost-effectiveness of tradable permits or grazing rights let us consider again our two herders – herder LMACH with low marginal abatement costs, and herder HMACH with high marginal abatement costs. Initially, both herders have grazing levels of A per year and both are allocated C permits. Figure 4.8 shows the marginal abatement cost curves for the two herders and how they react to the introduction of the permit market, given their abatement costs, permit allocation and the permit price.

Figure 4.8: Cost-effectiveness of a tradable permit system



Source: Adapted from Bright and Latacz-Lohmann, 1998

The right hand side of the diagram shows the permit market with Ē being the total number of permits brought into circulation and **p** being the equilibrium permit price. The left hand side depicts the marginal abatement cost curves for our two herders facing permit price **p**.

Herder LMACH's grazing level is initially A per year. With the permit system and the permit price set at **p** and the herder's initial allocation of permits set at C, the herder will face an economic incentive to reduce grazing to the level B, where marginal abatement cost is equal to the price. The herder will then be able to sell C – B permits at price **p**. If the herder LMACH decides to use their total initial allocation of permits, C, then for grazing level C – B, the permit price is above the marginal abatement costs and the herder is not minimizing costs.

Herder HMACH with higher abatement costs and the same initial permit allocation of C, would operate at optimal point D by buying permits for D – C grazing permits. The herder is not forced to reduce herd size to C where marginal abatement cost would be higher than the permit price.

This graphical exposition demonstrates how herders would choose the option best suited to themselves, taking into account their abatement costs and the permit price. The MAC for the herders are equal and both are equal to the permit price. Thus, a graphical proof has been provided that shows that a permit system leads to an equalization of marginal abatement costs of grazing control, which is the condition for cost-effectiveness.

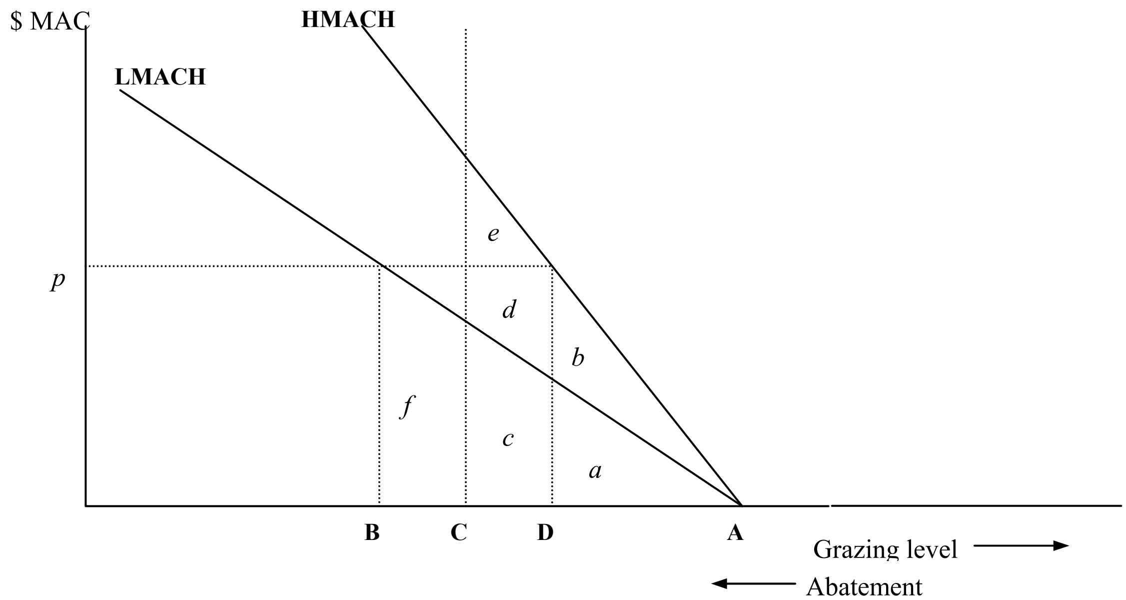
4.3.2.4 A cost-effectiveness comparative analysis

Now a comparative analysis of the cost effectiveness of standards, taxes and tradable permits or tradable grazing rights can be made. Let us compare the costs incurred by the two herders under a standard set at C, and with the permit market. This is illustrated in Figure 4.9.

Under the standard:

HMACH's abatement costs	= **a + b + c + d + e**
LMACH's abatement costs	= **a** + **c**
The total cost for the community with the standard	= **2a + b + 2c + d + e**

Figure 4.9: Cost-effectiveness of standards versus permits



Source: Adapted from Bright and Latacz-Lohmann, 1998; Field, 1994

Under the permit system:

HMACH's abatement costs = **a + b**

HMACH's transfer payment to LMAC by buying permits = **c + d**

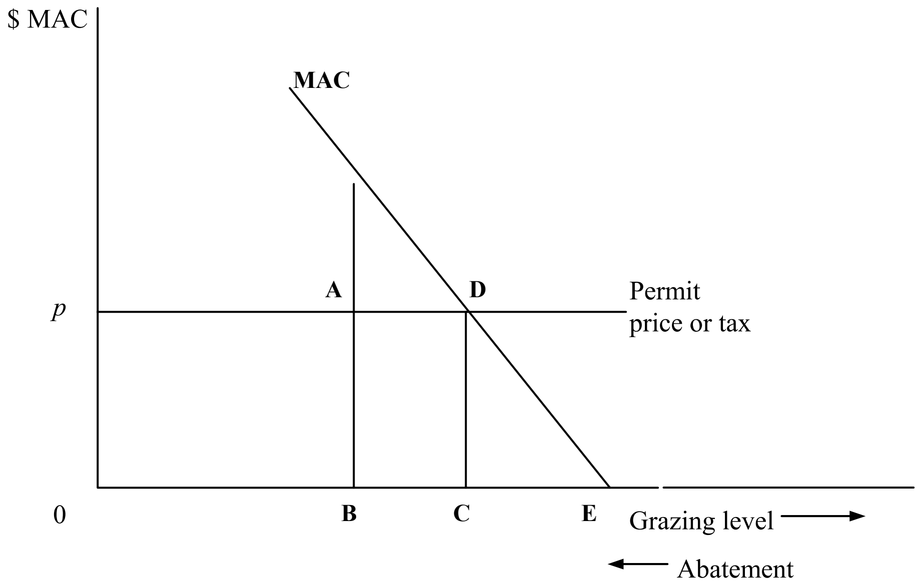
LMACH's abatement costs = **a + c + f**

LMACH's transfer payment for selling permits = **c + d**

The total cost for the community with the permit market = **2a + b + c + f**

Cost saving from using permits rather than a standard = **c + d + e – f**

Figure 4.10: Comparison of financial costs to herders of taxes and permits



Source: Adapted from Bright and Latacz-Lohmann, 1998

As BC = CD, c + d > f and there are, in theory, undoubtedly cost savings to be made from using tradable permits.

Figure 4.10 compares the financial costs facing a herder both under a tax and a permit system. Suppose the permit price is equal to the tax rate. MAC is the herder's marginal abatement cost curve, and B represents the initial endowment of permits.

There is no difference in abatement cost (area CDE) between taxes and permits. However, assuming that there are no tax exemptions and that the herder does not need to pay for the initial endowment of permits, taxes place a bigger burden on herders than permits:

- The tax liability is given by rectangle OpDC.
- The cost of buying the permits is represented by rectangle ABCD.
- Reduction in financial burden with the permit system = OpAB.

Thus, assuming that the initial allocation of permits is free, it can be concluded that the permit system is more cost-effective than the tax system. This section therefore concludes that, theoretically, the use of tradable grazing rights for grazing control is more cost effective than both standards and tax systems.

4.3.3 Equity Issues

4.3.3.1 Standards

The distributional impacts of standards have already been discussed. A uniform standard set for a community as a whole appears not to discriminate between producers. However, as has been already seen, herders may face very different costs of abatement. There is therefore a judgment to be made as to whether a standard is, in fact, fair to all producers. The general perception is that standards would pose a lower financial burden to herders than taxes, because herders would only incur the costs of grazing control and the additional tax liability does not hold.

4.3.3.2 Taxes

We reached the conclusion that taxes would place a double burden on herders in that herders would have to pay both the tax and the abatement costs. Some commentators consider this to be unfair, particularly because the tax liability exceeds the remaining environmental damage at the optimal level of grazing. The tax double burden could be reduced using any one of the following:

- Use the taxes collected as lump sum grants or subsidies to the herders, tied to the implementation of new abatement technology. However, although this would give the herders an incentive to introduce new technology (dynamic efficiency), there would be costs involved in monitoring whether the new technology is set in place.
- Exempt the first X animals that a herder has from tax.

- A system could be designed where certain number of cattle could be exempted, a further decrease in cattle numbers would attract a low rate of tax and an increase in cattle numbers would be taxed at a high level. This becomes increasingly difficult administratively, but does address the problem of the double burden.

4.3.3.3 Tradable permits

Much of the criticism leveled at marketable permit systems has revolved around issues of equity, fairness and morality. For example, is it right to permit environmental degradation rather than prohibit it? In fact, many consider permit systems as a sell-out of the environment. Is it right explicitly to subject the environment to market forces which, as is well known, may fail? There are a number of issues involved in this discussion, and the most important points will be reviewed here.

Assuming that the initial allocation of permits is free, the marketable permit system appears to be fairer in operation on herders than the use of taxes. However, the way in which the permit system is set up also needs to be evaluated using the fairness criterion. As was indicated before, the market for grazing rights can be set up by using grand-fathering or by holding an auction. A grand-fathering system discriminates against new entrants to the market in the short term, so it can be deemed unfair to new entrants. An auction system also has its drawbacks, as the herders have to pay the auction price for their first allocation of permits, and this represents a financial burden on herders equal to the burden under a tax system, possibly affecting their competitiveness.

Let us now turn to discuss whether marketable permits are fair to other groups in society. One complaint against permits, as we have already seen, is that they would give herders the right to damage the environment to a certain extent - as dictated by the number of permits issued for free. This is contrary to the Polluter Pays Principle (OECD, 1975), and environmental pressure groups would argue that the wrong signals are being sent to herders. Of course, marketable permits are not the only instrument with this property: standards are also in effect saying that a certain level of environmental damage is acceptable and give herders the right to damage the pastures up to that level allowed by the standard. The main difference, therefore, is not the property rights allocation but the tradability of TGR.

However, in theory, the permit market could be open to groups other than just the herders. This would give other interested parties, such as environmental groups, or indeed the government, the chance to enter the permit market. Environmental groups could buy permits and then not use them. The effect of this would be two-fold:

- It would reduce environmental damage by withdrawing grazing permits from circulation, and
- If the buy-out of permits were big enough, it would increase the price of the permits, as a smaller quantity would be available to buy. This increase in price would stimulate innovation for further environmental damage reductions.

Economists would strongly argue in favor of an open permit market because a buy-out of permits would indicate that society is willing to pay for further improvements in environmental quality. Hence, there is a net welfare gain to be achieved. In other words, the buying-out moves the system closer to the economic optimum. Although this is less relevant to the communal area situation, as grazing becomes scarcer and as the communities become wealthier, it could be relevant in the future.

It has been argued so far that the regulator requires full information to set policy instruments at the optimal levels. This becomes less important in an open-market permit system because it is the public's perception about the benefits of further reduction in environmental damage (rather than strict scientific evidence or proof) that leads the system to the optimum. In this respect, an open-market permit system could be considered a quasi-market for environmental quality in which environmental pressure groups mimic the demand side of the market, and herders offer the product 'damage reduction' based on their marginal abatement cost curves.

Another advantage of an open permit market is that it gives the regulatory body the opportunity to intervene and buy permits if it decided that damage needs to be further reduced. This gives the system much greater flexibility in adjusting to changing policy goals. This flexibility cannot be over-emphasized in its importance in addressing long-term sustainable and equitable growth.

One assumption that has been made in the discussion so far is that the market for permits acts competitively, but this may not be the case, which may have implications for the fairness of the system. For the market to work well, a large number of buyers and sellers in the market is needed. However, from the environmental point of view, we may wish the regulation area to be relatively small. For instance, if a pasture is badly damaged, the permit market needs to be restricted to herders of that particular pasture. Thus, the economic and environmental requirements for a successful market may be very different.

Even if the regulation area is big, a small number of "big" herders or even a monopolist may dominate the herders. Such herders may try to corner the market by hoarding permits and refusing to trade them, so creating a barrier to new herders joining the cattle industry. Thus, a grazing permit system can contribute to non-competitive behavior in the communal area cattle industry. This problem could be partly overcome if every adult individual in the community is given an equal number of permits every year or any pre-determined time period.

4.4 Monitoring and Enforcement

Grazing management involves high transaction costs, which also reduces an efficient allocation of grazing resources over time. Transaction costs involve information costs, enforcement or policing costs and contractual costs (Schmid, 1987, Randall, 1981). This section will focus on the implication of transaction costs on the implementation of tradable grazing rights. Focus is here given on TGR because they have been shown to be more cost-effective than standards and taxes, and they could be more equitable if appropriately implemented.

4.4.1 Information costs

Grazing management implies high information costs resulting from interdisciplinary research efforts in biology, ecology, statistics and socio-economics. This research is needed to keep track of: (1) cattle population dynamics and stock magnitude; (2) environmental variability; (3) spatial dynamics of different stocking rates; (4) changes in inter-temporal preferences of the society as a result of fluctuations in market demand and resource availability. Lack of information leads to: (i) poor grazing management and consequently overgrazing, and (ii) an increase in herding costs and the consequent reduction of the economic rent from the grazing resources. This situation becomes even more complex with the large uncertainties observed in natural systems, as well as in biological, social, political and economic factors (Hilborn and Peterman, 1996), thus increasing the probability of having non-contributing users, grazing depletion and economic rent dissipation. However these costs are relevant to any of the grazing management systems – standards, taxes and tradable permits.

4.4.2 Contractual costs

This type of transaction costs will be incurred when legislative efforts are directed to promote collective forms of organizations, giving herders exploitation rights over grazing resources. In this context, costs directed to foster this kind of organizations are usually substantial, so it will be necessary to identify who (e.g. herders or the State) will pay for the contractual costs. This will happen when the State will promote a grazing management strategy, such as the implementation of tradable grazing rights (Geen and Nayar, 1988; Seijo, 1993) amongst the members of a community in order to maximize resource rent over time.

4.4.3 Enforcement costs

Grazing management involves high enforcement or policing costs resulting from the implementation of management schemes and allocation of property rights. Unlike in fisheries where policing areas are so extensive (oceans) (Defeo et. al., 1993), policing areas in the communal areas may not be termed extensive if property rights are instituted. As will be shown in this study, households and hence communities know the boundaries of their grazing areas and these are within the easy reach of all community members. This is shown by the ability of households to take their cattle to the pastures and penning them on a daily basis (Muchena, 1993).

Enforcement costs involve (Spulber, 1988):

- Monitoring costs including costs of detecting violations of the regulation, and
- Costs of imposing penalties, or other legal costs.

This thesis will, however, not explore, *ex ante*, the economics of enforcement of environmental policy with specific reference to tradable grazing rights. These costs would probably be considerably higher with standards or taxes since there would be no incentive to regulate neighbors.

4.5 Summary

This Chapter presented the theoretical framework of the study. The framework presented here is an adaptation of work mainly on fisheries resources management and pollution control. A comparative analysis of the cost-effectiveness and equity implications of TGR, tax and standards was made. The theoretical comparative analysis of standards, taxes and tradable permits shows that tradable permits are more cost-effective and more equitable than standards and taxes.

TGR systems, however, involve significant management difficulties. For the system to succeed it must be rigorously enforced since cheating on grazing rights might be highly profitable. The ideal and more cost-effective system would be for the cattle owners themselves to be responsible for enforcement. After all, any grazing right cheaters would be robbing their fellows.

The propensity for grazing resources to fluctuate unpredictably, due to fluctuations in rainfall, leads to difficulties in the management program. Grazing shares need to be adjusted annually or whenever required to match the available range biomass. The grazing rights would therefore require perpetual adjustment, often with little advance warning. Equally important, cattle numbers must be regularly assessed and this is an expensive proposition unless it is managed by the community of herders, with the provision to reduce opportunities for monopoly control.

To empirically motivate the TGR model intuitively developed in this chapter, a recursive bio-economic LP model will be developed to assess the efficiency, equity and food security impacts of adopting TGR for grazing control.

CHAPTER V: RESEARCH METHODS

5.0 INTRODUCTION

This chapter presents the research methods used for the study. This includes a discussion of site selection; household sampling; designing and implementation of questionnaires; data entry and cleaning.

5.1 Sites Selection

The research for this study was carried out in Chiduku and Buhera Communal Areas (CA). Chiduku CA is about 230 km East of Harare whilst Buhera CA is about 250 km South-East of Harare. Two VIDCOs[13] were selected for each communal area to answer the research questions proposed for this study. The two VIDCOs in Chiduku CA are Matsika in Natural (Agro-ecological) Region[14] II and Chiduku VIDCO in natural region (NR) III. The two VIDCOs for Buhera CA are Nerutanga in NR III and Gaza-Chifamba in NR IV.

These communal areas were selected for the study because they are close to each other. This provided an opportunity to study communities with varying demographic and agro-ecological characteristics that are in close proximity. On average, Buhera CA has a lower population density than Chiduku CA. Since Chiduku and Nerutanga VIDCOs are in the same agro-ecological region, differences in results between these two are expected to be due to factors other than agro-ecological region.

Initial contacts were made with the respective District Councils for the two communal areas who gave permission to work in the study areas. Contacts were then made with traditional leadership, WARD councilors and VIDCO chairmen. In each study site awareness meetings

[13] A VIDCO is an administrative unit with about 100 households. About six VIDCOs form a WARD; a number of WARDS form a District; a number of districts form a Province. Like in this case, the study sites are in the Manicaland Province, of the ten provinces of Zimbabwe. Nerutanga VIDCO is in WARD 4 whilst Gaza is in WARD 10. Matsika and Chiduku VIDCOs are both in WARD **1**.

[14] Zimbabwe is divided into five Natural (Agro-ecological) Regions on the basis of rainfall, soil and vegetation characteristics. Natural Region 1 receives the highest rainfall and is agriculturally fertile. Natural Region 5 is the driest part and is not suitable for intensive crop production (Vincent and Thomas, 1962).

were organized with the aid of local leadership. Following these arrangements, group interviews and survey data collection were carried out during the months of September and October 1999.

5.2 Questionnaire Designing and Implementation

Based on group interviews in the four VIDCOs, as well as literature review, four questionnaires were designed. The questionnaires were pre-tested during the enumerator training sessions on how to implement the questionnaires. The data collected per questionnaire is summarized below and details are given in Annex 1.

Questionnaire 1:

a. Household characteristics: household size, gender of household members, ages of household members, education level of household head and the employment status of household head,
b. Land holding and the size of land under fallow,
c. Livestock production: number of livestock kept by type, cattle herd composition, cattle herd performance parameters from 1989 to 1999, household purchases of cattle feeds,
d. Ranking of alternative sources of household income,
e. Membership into farmer organizations and contact with extension,
f. The adequacy of the current cattle herd for meeting household needs and the additional number of cattle needed to meet these needs if the present herd is not adequate,
g. The number of cattle households are willing to sell at different hypothetical cattle prices,
h. The importance attached to grazing resources compared to arable land holding,
i. Household willingness to pay for grazing,
j. Household commitment to conserving grazing: attendance of meetings on grazing management and the household willingness to attend future meetings,
k. Household time preference of grazing resource use: whether to graze as much as possible today or to conserve grazing, and
l. Household preference of authority over natural resource utilization.

Questionnaire 2: The data collected using questionnaire 2 covers:

a. Crop production: crops grown, the area under crops, crop output and sales from 1989 to 1998,
b. Cash income obtained from non-agricultural sources,
c. Household consumption of common property resources (CPRs) and the availability of CPRs over time, and
d. Estimates of cash and in-kind income derived from the use of CPRs.

Questionnaire 3: The data collected using questionnaire 3 covers:

a. Household preference of alternative grazing management options: TGR, individualization of grazing, taxing cattle owners, establishment of grazing schemes, community grazing management, fodder production and continuing with the present practice. Under the proposed TGR policy, households only buy grazing shares for all cattle above four. For cattle less or equal to four grazing is not paid for.
b. Household willingness to pay (WTP) and willingness to accept (WTA) for grazing rights,
c. The number of cattle households would keep at different hypothetical grazing right prices,
d. Household willingness to pay (WTP) taxes, and
e. The number of cattle households would keep at different hypothetical tax rates.

Questionnaire 4: The data collected using questionnaire 4 covers:

a. Ownership of private plots for grazing cattle,
b. Rules governing grazing resource use: location or boundary rules, authority rules and rules on the maximum number of cattle a household can keep,
c. If households comply to these rules, penalties for not complying with these rules and anyone who has been sanctioned for violating any of these rules,
d. Household perceptions on the establishment of new rules on grazing resource use, would households comply to these new rules,
e. Household willingness to monitor other households and to be monitored by other

households on grazing resource use,

f. Household perceptions on the trend in crop and livestock productivity. If these trends are decreasing over time whether they think these are due to overgrazing and soil erosion, and
g. Time period since the household started farming in the community.

5.3 Secondary Data Collected

To develop production functions to be used in determining the cost-effectiveness and equity implications of implementing TGR, the following secondary time series data (1954 - 1997) was collected for each communal area: rainfall figures[15], cattle populations, area under major crops, and yields of major crops[16]. Other secondary data collected specific to the sites include total land area in the research site, human population estimates, and estimates of current cattle productivity parameters. To estimate the total land area covered by each survey site, community members were asked to demarcate vidco boundaries on a base map. These maps were then scanned. Using the MapMaker Pro program, the scans were calibrated and used to estimate the area under each survey site.

5.4 Selection of Sample Households

For each VIDCO, the target population was identified as all households being member of the village. The household or the community/vidco is used as the unit of analysis in different chapters to address different research hypotheses. A household is defined as a nuclear family unit, consisting of (a once) married adult(s) and the unmarried children, which is registered as a member household of the VIDCO (Waeterloos and Guveya, 1993).

For each VIDCO, the VIDCO chairperson and village headmen provided a list of household membership to the VIDCO. In the participatory research phase, during group discussions, these lists were checked for missing households and then completed with data on livestock ownership and the sex of heads of households for stratification purposes. The lists were completed with data

[15] Rainfall figures were collected from the meteorological office in Rusape Town for Chiduku Communal Area and Buhera Center for Buhera Communal Area

on the wealth status of each household and on the information of whether a household was residing in lands designated for grazing or not.

Households that were indicated to be absent during the compilation of the sampling frame were excluded from the sampling list. Absence refers to a case where both husband and wife are away from the village during the period of the survey and either one or both are searching for employment or employed outside the village. Since absent households were deleted from the sampling list, for the purposes of this study, the target population is different from the study population.

Each household was scrutinized on ownership of cattle and settlement into grazing areas by means of a dichotomous yes (if it owns cattle) or no (if it does not own cattle) variable. Three values were ascribed to the sex of head of household: male head present, *de facto* female head if the husband is absent, and widowed. Three values were also ascribed to the wealth status of the household: rich, medium and poor.

For the wealth ranking exercise, four to six local farmers were asked to define or identify variables that are considered by the local community to distinguish between the rich and the poor and to rank households on the sampling lists based on these criteria[17]. After these were defined, two or three groups (each group comprised of three to five members) of farmers separately categorized the households as rich, medium or poor. The results of the ranking exercise by each group were compared. In the majority of cases the ranks were the same. In the cases were the ranks were different a consensus was reached on which wealth categories to place the households.

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[16] Agricultural production data was collected from the district Agritex Offices (now AREX)

[17] Rich households are perceived as those households with large cattle herds, have scotch carts, plows, large land holdings, brick and asbestos roofed houses, they are able to sent their children to school, they are also good farmers who realize high crop yields and are thought to have a lot of money. On the other extreme poor households have few or no cattle, they do not have the any of the major farming implements, they have difficulties in sending their children to school and they work as casual laborers for the rich and medium rich households. In between these two extremes are the medium rich households. There are a few cases where households were classified as rich but they did not have cattle and the major farming implements.

Sample sizes of 100 households in each of the four study sites were opted for, to give a total study sample of 400 households. The selection of the sample households was done by stratified random sampling.[18] The stratification was based on whether a household had cattle or not. In each stratum a random selection of households was performed. The study population and sample proportions stratified by cattle ownership for the four study sites are shown in Table 5.1. The study sample seems to represent the study population well. This is indicated by the similarity in the percent households with and without cattle between the sample and study populations.

Table 5.1: Stratification of study population and sample households by cattle ownership by survey site

	BUHERA CA		**CHIDUKU CA**	
	Nerutanga	**Gaza**	**Chiduku**	**Matsika**
# of HH[+] in study population	132	162	243	161
Sampling proportion (%)	75.8	61.7	41.2	62.1
% HH in study population with cattle	70.5	57.0	49.0	59.0
% HH in the sample with cattle	72.0	53.0	66.0	51.0
% HH in study population without cattle	29.5	43.0	51.0	41.0
% HH in the sample without cattle	28.0	47.0	34.0	49.0

[+] HH is households.

5.5 Enumerator Selection, Training and Survey Implementation

Whilst the sampling frames were being constructed, potential enumerators were interviewed. The interviews were in two phases. The first phase was a written interview that involved comprehension, simple mathematics and translation of passages from English to Shona (the local vernacular) and vice versa. This was done to make sure that those who had serious difficulties in translation were eliminated from the outset and also to ensure that the selected enumerators wrote eligibly. The second phase was an oral interview. The oral interview involved translations and other general issues like one's family and educational background. This was done to ensure that the selected enumerators could communicate verbally. In each of the four study sites 10

[18] A stratified random sample is a sample that is obtained by separating the population elements into non-overlapping groups, called strata, and then selecting a simple random sample from each stratum (Scheaffer, Mendenhall and Ott, 1990). By stratifying the sample, the parameter estimation is improved.

enumerators were selected. The enumerators interviewed members of their own VIDCOs so that respondents were comfortable answering questions from interviewers they know and are familiar with.

After enumerator selection, enumerators were trained in all aspects of data collection using questionnaires. A training manual was designed to aid training. Each group of enumerators was trained separately to ensure maximum participation of the enumerators during training. The training session for the first questionnaire was done over two days. Training for subsequent questionnaires was done over 1-day sessions. Enumerators administered each questionnaire just after each training session. During the implementation phase enumerators were closely monitored to ensure quality data collection. The filled in questionnaires were handed in at the end of each day's work. Each questionnaire was scrutinized for mistakes and missing data. Where deemed necessary some interviews had to be repeated. Each of the questionnaires was administered over three days with each enumerator interviewing between three and four households per day.

5.6 Data Entry and Cleaning

Data entry was done in SPSS. Data cleaning was done, first by running frequencies in SPSS and checking for obvious mistakes in the entries. Then the data was printed out verified entry by entry for a sample (10 percent) of the questionnaires. Secondary data was entered in Excel. Data analysis was done in SPSS, SHAZAME, Excel and LINGO.

5.7 Summary

For the study, Buhera and Chiduku communal areas were selected. Two study sites were selected in each communal area. In each study site a sampling frame was developed. Households were stratified into cattle owning and non-cattle owning households. A stratified random sample was selected from each of the four study sites, resulting in 100 households being selected per site. Thus a total sample size of 400 households was selected.

CHAPTER VI: ARE COMMUNAL AREA RANGELANDS OVERGRAZED OR OPEN ACCESS OR BOTH?

6.0 INTRODUCTION

The main objective of this Chapter is to assess if the communal area rangelands are overgrazed, open access, or both. The main hypotheses being tested are that (i) rangelands in the study areas are overgrazed, and (ii) rangelands in the study areas are open access resources.

The chapter commences with an analysis of the household characteristics that may have an implication on collective action for grazing resource use and management in the communal areas. In Section 6.2, the indicators of overgrazing are estimated and analyzed to determine whether grazing lands in the communal areas are depleted. Attitudes and preferences towards the use and investment in sustainable grazing resource use are presented in Section 6.3. It is hypothesized that households have a positive time preference and therefore tend to graze as much as they can today than to defer grazing into the future. Using the property rights framework, Section 6.4 assesses whether grazing resource use in the selected communal areas is open access or not.

6.1 Household Demographic, Educational and Employment Characteristics

Table 6.1 shows the household head demographic, educational and employment characteristics. On average Chiduku CA have a higher percentage of *de facto* female-headed households than Buhera CA. On average Buhera CA have a higher proportion of widowed households than Chiduku CA. The percentage distribution of male-headed households is similar between the two communal areas. At least forty percent of the households are male headed, across survey sites. The percentage distribution of households within wealth, education and employment status categories is similar across all the survey sites. Poor households constitute the majority in all survey sites except in Matsika Vidco where the medium households are the majority. The majority of household heads attained primary education and are farmers. The mean household size is also similar across survey sites with four people per household.

Across all the survey sites there is some encroachment onto grazing land (Table 6.2). Encroachment is measured by the percentage of households living and cultivating on areas designated for grazing. Encroachment is most serious in Gaza and Matsika and is the least in Nerutanga. Encroachment reduces the area under grazing, increases the grazing pressure and hence enhances the rate of rangeland degradation. Rangeland degradation will continue if no efforts are made to improve the rangeland quality e.g. planting of legumes and high yielding grasses or buy feed supplements for cattle, or any other form of effective rangeland management.

Table 6.1: Demographic, educational and employment characteristics of household heads by survey site

Household attribute	BUHERA CA		CHIDUKU CA	
	Nerutanga	Gaza-Chifamba	Chiduku	Matsika
Sex of HHH (% HH)				
- Male	40.0	45.0	42.0	44.0
- De facto female	29.0	32.0	37.0	36.0
- Widow	31.0	23.0	21.0	20.0
Wealth status HH (%HH)				
- Rich	4.0	11.0	11.0	19.0
- Medium	32.0	34.0	38.0	43.0
- Poor	64.0	55.0	51.0	38.0
Mean age of HHH (years)	54.0	50.1	53.4	50.9
Education HHH (% HH)				
- No education	18.0	16.0	13.0	16.2
- Primary education	59.0	54.0	73.0	58.6
- Post-primary education	23.0	30.0	14.0	25.2
Employment status (%HH)				
- Farmer	72.0	51.5	92.0	85.0
- Local non-farm	23.0	42.4	6.0	10.0
- Non-local non-farm	5.0	6.1	2.0	5.0
Mean HH size	3.8	4.4	4.7	4.1
N	**100**	**100**	**100**	**100**

HH – Household HHH - Household head

The average farm size and average percentage area under fallow are so small that it is impossible for households to be able to graze their cattle on individual farms (Table 6.2). At most six percent of the households across survey sites indicated that they have private plots where they graze their cattle. None of the households indicated that they buy feed supplements to feed their cattle. Thus, the major source of grazing is the communal rangelands (all year round) and crop residues (mainly during the dry season).

Table 6.2: Mean farm size and area under fallow by survey site

Household attribute	BUHERA CA		CHIDUKU CA	
	Nerutanga	Gaza-Chifamba	Chiduku	Matsika
Farm size (ha)	1.98	2.19	1.58	1.84
Area under fallow (ha)	0.33	0.38	0.31	0.15
Area under fallow (%)	15.24	18.27	20.58	11.74
% HH staying on grazing land	11.0	35.0	25.0	36.0

6.2 Indicators of Overgrazing in the Communal Areas

To assess the extent of overgrazing in the study sites, the following indicator variables were analyzed:

- The number of cattle owned over the period 1954 to 1999 and the corresponding stocking rates or grazing pressure,
- Household response to crop and livestock policies,
- Household perceptions of the adequacy of grazing,
- Households perceptions of the degree of overgrazing,
- Percentage households producing fodder,
- Household perceptions of trends in milk output, draft power supply and crop yields, and
- Household grazing time preference.

6.2.1 Trends in grazing pressure (1954 – 1999)

The recommended stocking rates for the communal areas are based on recommendations for beef production systems (Muchena, 1993; Scoones, 1990; Chinembiri, 1989) where conservative stocking rates for maximizing weight gain are required. These official carrying capacity measures use indicators that underestimate potential stocking rates by ignoring key grazing resources like browse and crop residues. Scoones (1990) and Arntzen (1990) estimate that the "official" carrying capacity is between 0.54 and 0.75 of estimated stocking rates (ha LU^{-1}) for communal areas.

An indicator for grazing pressure used for the survey sites is the number of stocker days per hectare per annum. The stocker days are obtained as follows. Stocking rate (SR) is defined as the number of cattle/stockers grazing per hectare over a grazing period of length $\boldsymbol{v}$, and SD is the number of stocker days grazing per ha i.e. SD = $\boldsymbol{v}$ **.** SR (Hart et. al., 1988). GP is current period grazing pressure measured in stocker days of grazing per unit of standing herbage (H) produced.

$$GP = SD/H = \boldsymbol{v}.SR/H \qquad (6.1)$$

This standardization adjusts for grazing intensity differences as forage production varies between years because of weather and other environmental factors (Vallentine, 1990). Given the level of rainfall, the area under cultivation and the area under grazing, equation (6.1) is used to estimate the recommended SD ha^{-1} yr^{-1}.

Adapting from the work by de Leeuw and Tothill (1993) and Behnke et. al., (1993), given the rainfall level, the available gross dry matter range feed production in kilograms per hectare (RY) is:

$$RY = (0.1 + 0.00325*Rainfall)*1000 \qquad (6.2)$$

The rainfall is total rainfall received. So taking into account a run-off of 16.5 percent (Behnke et. al., 1993), the effective rainfall is at 83.5 percent. Thus (6.2) becomes:

$$RY'' = (0.1 + 0.002714*Rainfall)*1000 \qquad (6.3)$$

Not all herbage produced on the rangelands is available for utilization by livestock. Some herbage needs to remain for protective cover. The protective cover herbage is estimated at 200 kilograms per hectare (Behnke et. al, 1993). Hence the available dry matter yield (ARY) is:

$$ARY = RY'' - 200 \tag{6.4}$$

To get the total available range feed production (TARF) per year, the ARY is multiplied by the area under grazing (agrz), i.e.:

$$TARF = agrz*ARY \tag{6.5}$$

In the communal areas, livestock feed is also obtained from crop residues, especially during the dry season. So the dry matter feed available from cultivated lands (CF) in kilograms is:

$$CF = armz * MZYild*coeff \tag{6.6}$$

where armz is the estimated area under maize cultivation,

MZYild is maize grain yields in kilograms per hectare, and

coeff is the conversion factor from maize grain yields to stover yields. The conversion factor is assumed to be one[19] (Guveya, 1995).

So the total feed available from both the rangelands and stover per year (H), in kilograms is:

$$H = CF + TARF \tag{6.7}$$

[19] Given that the conversion factor from maize grain yields to maize stover yields is 2.2 (Steinfeld, 1988), the analysis presented in this thesis assumes that about 45 percent of the total stover produced is fed to livestock.

Given that one livestock unit requires an amount of 8 000 kilograms DM per year[20] (Cossins and Upton, 1987), the estimated carrying capacity (CC) for an area per year is the total feed available divided by the feed requirements per livestock unit per year. Multiplying the resulting figure by 365 and dividing by the gross area under grazing (rangeland area plus area under cultivation) gives the recommended stoker days per hectare per year (RSD), i.e.

$$RSD = \frac{365 * CC}{TGRA} \tag{6.8}$$

Where TGRA is armz plus agrz. The estimated actual stoker days per year (ASD) is obtained by simply multiplying the estimated number of cattle per year by 0.8 (to convert cattle numbers to their livestock units equivalent), multiply the resulting figure by 365 and dividing by TGRA, i.e.

$$ASD = \frac{365 * LU}{TGRA} \tag{6.9}$$

Where LU is livestock units. The estimated actual and recommended stoker days per survey site over a 45-year time period are compared in Table 6.3. During periods when there is overstocking, ASD > RSD. Similarly, during periods when there is no overstocking, RSD => ASD. Table 6.3 also presents the overstocking probability per period. For example, in Nerutanga, during the ten-year period 1971 to 1980, there is overstocking in five of the ten years, hence the probability of overstocking during that period is 0.5 or 50 percent. Over the 45-year period the probability of overstocking in Nerutanga is 0.32 or 32 percent.

Table 6.3: Trends in stocker days per ha per year (1954 – 1999) by survey site

	NERUTANGA			**GAZA**			**CHIDUKU**			**MATSIKA**		
Period	**ASD**	**RSD**	**OP**	**ASD**	**RSD**	**OP**	**ASD**	**RSD**	**OP**	**ASD**	**RSD**	**OP**

[20] Other authors indicate that a tropical livestock unit (TLU) of 250 kg weight requires 2300 to 2700 kg DM feed per annum (de Leeuw and Tothill, 1993; Braat and Opschoor, 1990). For purposes of this thesis the 8000 kg DM feed requirements per LU per year is used to simulate the worst case scenario which gives conservative estimates for grazing pressure and carrying capacity.

1954 – 1960	38	91	0.00	32	75	0.00	44	93	0.00	33	99	0.00
1961 – 1970	48	83	0.10	40	65	0.10	55	74	0.20	41	91	0.00
1971 – 1980	62	110	0.50	52	76	0.10	72	92	0.10	53	113	0.10
1981 – 1990	76	91	0.40	63	58	0.70	87	76	0.80	65	102	0.10
1991 – 1999	79	81	0.56	66	51	0.56	92	68	0.89	67	82	0.44
Mean	61	92	0.32	51	65	0.30	70	80	0.40	51	99	0.13

ASD – Estimated actual SD RSD – Estimated recommended SD OP–Overstocking probability

The mean ASD shows that grazing pressure is highest in Chiduku followed by Nerutanga. The mean grazing pressure is similar between Gaza and Matsika. Across all survey sites, the GP more than doubled over the 45-year period. Comparing the ASD and RSD per survey site over time shows that:

- Nerutanga and Matsika are not yet over grazing. Given the relatively high rainfall levels in these two areas, grazing pressure seem to be approaching carrying capacity during the 1990s. This is particularly so in Nerutanga.
- The overstocking probability (OP) results show that although Nerutanga and Matsika are on average not overstocked, depending on the level of rainfall, there is overstocking in some periods. For example during the period 1971 – 1980, Nerutanga is overstocked for five of the ten years during that period. Similarly, during the 1991 – 1999 period, Matsika is overstocked for four of the nine years.
- Gaza and Chiduku has been overgrazed since the 1980s. The overgrazing is greater in Chiduku. On average, Gaza is overstokcked by about 9 percent and Chiduku by about 15 percent during the 1980s. During the 1990s, Gaza is overstocked by 29 percent whilst Chiduku is overstocked by 35 percent.
- The OP results for Gaza and Chiduku show that the two survey areas are overstocked for six to nine years in each of the ten-year periods since 1981.

Based on these results, in can be concluded that Chiduku and Gaza may be overgrazed. The results also show that basing conclusions on the grazing pressure alone may be misleading. The actual grazing pressure has to be compared to the recommended grazing pressure.

Table 6.4 explains the source of the increasing grazing pressure over time. Across all the study sites the mean number of cattle owned per household is decreasing over time.

Table 6.4: Mean number of cattle owned*, the number of cattle owners and the total number of cattle owned by sample households by survey site

Year	BUHERA CA						CHIDUKU CA					
	Nerutanga			Gaza			Chiduku			Matsika		
	Mean	No. HH+	Total cattle	Mean	No. HH	Total Cattle	Mean	No. HH	Total cattle	Mean	No. HH	Total cattle
1999	4.0	81	324	4.0	60	239	4.1	74	303	4.2	63	265
1998	4.3	87	374	4.1	57	234	4.5	74	333	4.4	58	255
1997	4.6	72	333	4.2	53	222	4.7	66	312	4.6	51	234
1996	5.6	70	395	4.0	53	214	4.9	62	306	5.3	48	252
1995	5.6	63	354	4.3	48	205	5.3	53	280	5.2	41	211
1994	5.6	56	314	4.2	44	184	5.3	47	247	5.2	37	193
1993	5.7	47	267	4.3	45	195	5.6	42	234	5.6	36	200
1992	5.7	42	238	4.9	44	216	7.1	39	277	5.7	41	234
1991	7.7	36	278	5.6	47	261	8.1	35	282	6.2	40	248
1990	7.1	33	234	5.9	43	255	8.0	30	239	7.3	34	249

*The mean number of cattle owned is only for cattle owners for the respective year.
+ Household

This decrease in herd size per household is most likely due to the occurrence of two serious droughts during the period of assessment (1988 and 1992) which claimed a lot of cattle. What is also clear is that the number of cattle owners is increasing over time. The increase in the number of cattle owners overrides the decrease in the number of cattle per household to result in an overall increase in cattle numbers over time.

The results of Tables 6.3 and 6.4 mean that over time the pressure on grazing resources is increasing. From an economic view point, households are still realizing positive “rents” or “profits” from grazing resource use and this is attracting new entrants into owning cattle. Whilst grazing resource use is free, in the sense that farmers do not pay to graze their cattle, farmers are getting the benefits of manure, milk, draft power, and occasional sales. In the long-run, as more and more farmers own cattle, on fixed or shrinking rangelands, the rents from grazing resource use will be dissipated. Hence there is need for forward planning to ensure sustainable grazing resource management.

The policy implications of this observation are that a focus on grazing control could be made on two fronts:

- Limiting the number of cattle owned per household, and/or
- Limiting the number of cattle owners.

Since the number of cattle owned per household is decreasing over time, then the policy challenge is on how to restrict the number of households owning cattle whilst ensuring that, at the community level, the maximum net benefits of keeping cattle are fully realized. Alternatively, those with relatively larger herds can be made to reduce their cattle numbers by use of targeted economic incentive packages or mechanisms. In this thesis, it is argued that both outcomes can be achieved by use of tradable grazing rights (Chapter 9), at least in the short-run.

6.2.2 Household response to crop and livestock pricing policies

In the absence of time series data specific to the study sites to show the relationship between cattle prices and off-take, this section concentrates on households' respond to hypothetical increases in:

a. Cattle prices,
b. Crop prices, and
c. Crop yields.

This analysis was done to test the hypotheses that:

i. Households keep cattle as a source of manure and draft power to increase crop yields. If crop yields were to increase due to some other factors other than the number of cattle owned, then households would increase cattle off-take. Thus, an increase in crop yields would result in a reduction in stocking rates. However, if ownership of cattle is associated with higher crop yields, then higher stocking rates will be observed.

ii. Households sell their cattle only when some cash needs arise. When the relative price of cattle increases, households sell fewer cattle than they would without the price increase to meet their cash needs.

iii. If crop prices increase and households are producing a surplus, households do not sell their cattle to meet their cash needs. Cash needs are met through crop sales, *ceteris paribus*.

The results show that the major reason households sell their cattle is to meet household cash needs during times of distress (Table 6.5). Few households sell their cattle as a response to high cattle prices. At most, 30 percent of the cattle owning households in Nerutanga sell cattle in response to high cattle prices. Even then, the results show that unless the cattle prices are very high, households are not willing to increase cattle off-take. At most about 29 percent of the cattle owning households in Gaza would sell their cattle only when the price of cattle is very high (Table 6.6)

If crop yields or crop prices were to increase and farmers were producing a surplus, from about 78 percent of the households in Nerutanga and Matsika to 90 percent of the hoseholds in Gaza would sell fewer cattle (Table 6.7). The high crop yields would mean the ability of the households to meet food requirements. The disposable income from crop sales would be used to meet household cash needs and hence the little needs to sell cattle. If enough cash is generated households would actually purchase more cattle from the crop sales proceeds.

Table 6.5: Percent Cattle Owners Indicating Major Reasons for Selling Cattle by Survey Site

Response to cattle price increases	Buhera CA	Chiduku CA		
	Nerutanga	Gaza	Chiduku	Matsika
High cattle prices	30.4	5.8	7.6	8.3
Cash needs	60.9	90.4	84.8	91.7
When cattle are too old	0.0	3.8	1.5	0.0
Donot sell cattle	8.7	0.0	6.1	0.0

Forty-three percent, 61 percent, 62 percent, ad 87 percent of the households in Chiduku, Gaza, Nerutanga, and Matsika respectively would increase the area under crop cultivation if crop prices were to increase. This would imply a decrease in the area under grazing and hence an increase in the stocking rates. Thus, the hypothesis that an increase in crop yields would result in a decrease in stocking rates is rejected.

Table 6.6: Percent Cattle Owners Indicating Response to an Increase in Cattle Prices by Survey Site

Response to cattle price increases	Buhera CA	Chiduku CA		
	Nerutanga	Gaza	Chiduku	Matsika
Increase cattle sales	47.8	19.2	21.2	18.8
No change in cattle sales	30.4	25.0	31.8	39.6
Decease cattle sales		17.3	4.5	4.2
Increase sales only at very high prices	13.0	28.8	15.2	16.7
No cattle sales	8.7	9.6	27.3	20.8

Table 6.7: Percen Cattle Owners Indicating Response to An Increase in Crop Yields or Prices on Tillingness to Sell Cattle by Survey Site

Response to cattle price increases	Buhera CA	Chiduku CA		
	Nerutanga	Gaza	Chiduku	Matsika
Sell more cattle	4.3	0.0	6.1	0.0
Sell less cattle	78.3	90.4	81.8	78.7
Dont know	17.4	9.6	12.1	21.3

In summary, the results show that a rise in cattle prices may not make households sell-off more cattle. Also, an increase in crop yields and crop prices are not likely to result in high cattle off-take rates either. It can therefore be inferred that cattle are kept as a capital asset targeted at crop production and as the number of cattle increase, the asset base of the household increases. It can be concluded that the low cattle off-take rates and the resulting high stocking rates can be explained by the following factors:

a. Households keep cattle as a source of manure and draft power to increase crop yields.
b. Households sell their cattle only when some cash needs arise. When the relative price of cattle increases, households sell fewer cattle than they would without the price increase to meet their cash needs.

c. If crop prices increase and households are producing a surplus, households do not sell their cattle to meet their cash needs. Cash needs are met through crop sales, *ceteris paribus*. It is only when there is no other sources for cash that cattle are sold.

6.2.3 Perceptions towards adequacy of grazing resources

Households were asked of their perception of the adequacy of grazing for their cattle. Figure 6.1 shows that the majority of the households in Nerutanga perceive their grazing to be adequate. About a third of the households in Matsika perceive grazing to be adequate, whilst between 40 percent and 50 percent of the households in Gaza and Chiduku perceive grazing to be adequate.

This may be an indication that Nerutanga is not overgrazed whilst Matsika is likely to be overgrazed. This observation is complemented by household responses to the perceived degree of overgrazing (Table 6.8). Except for Nerutanga, at least 59 percent of the households across survey sites indicated that grazing resources are moderately to seriously overgrazed.

Figure 6.1: Percent households indicating they have adequate grazing for their cattle

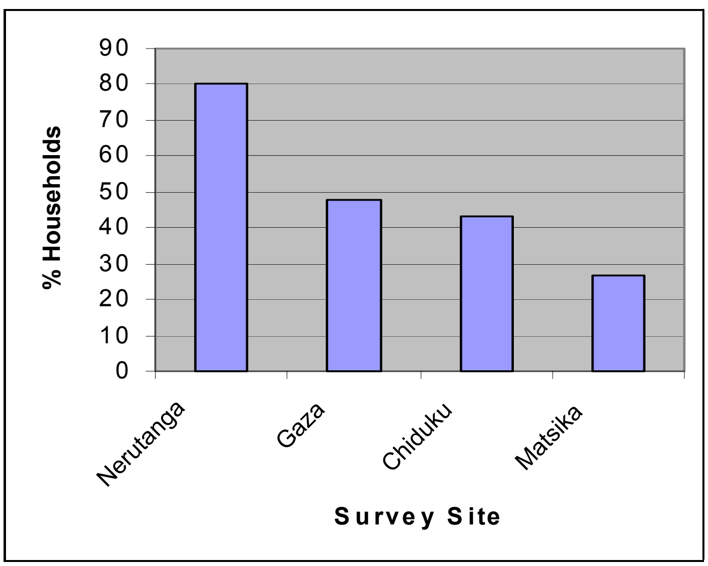


Table 6.8: Percent households[+] indicating the degree of overgrazing by survey site

	BUHERA CA		CHIDUKU CA	
Perceived Degree of Overgrazing	Nerutanga	Gaza	Chiduku	Matsika

Serious	3	20	18	33
Moderate	38	39	53	35
None	52	25	22	24
Don't know	7	16	7	8
N	20	52	57	73

+ As percent of those who perceive they do not have adequate grazing only

The major reasons for the perceived overgrazing are, in order of importance:

- There is little land for grazing,
- Households do not sell their cattle, and
- Households from other communities graze on local grazing lands.

These reasons are an important input into grazing policy i.e. policy will need to deal with the land question within communities and inter-community relations with respect to keeping cattle. Incentives have to be developed to encourage higher off-take to reduce the number of cattle on the rangelands.

6.2.4 Fodder production

If there is overgrazing in the communal areas of Zimbabwe, one would expect cattle owning households – in addition to collecting maize stover for storing on raised platforms in and around the cattle pens - to produce fodder to supplement their cattle feed. The results of the analysis show that in Nerutanga, Gaza, and Chiduku none of the households are producing fodder along contours. Only thirteen percent of the households in Matsika produce fodder along contours. Based on this result only, grazing is likely to be scarcer in Matsika than in the other survey sites.

Households were asked if they produce fodder in their fields. Two percent, one percent, four percent and one percent of the households in Nerutanga, Gaza, Chiduku and Matsika respectively produce fodder in their fields. This result may be interpreted from two angles. First, the low percentage of households producing fodder may be an indicator of low grazing pressure in the communal areas. Secondly, this may be interpreted as the case of free-riding and hence open access to rangeland use irrespective of whether the rangelands are overgrazed or not. Each household use as much of the grazing resources as they can; as long as there is some grazing available, it is cheaper for a household to graze on the commons than to produce fodder. A household will only produce fodder when the available grazing is no longer adequate to sustain household cattle.

Other contributory factors to the non-production of fodder include:

- Land scarcity: There is not enough land for households to produce enough grain to meet household needs. If fodder, is to be produced, it could be done along the contours or fodder production technologies are introduced that complement crop production.
- Scarce seasonal labor: If the fodder technology has high labor demands, especially during the cropping season, it may not be taken up.
- Scarce capital (physical and financial): the fodder plots will need to be protected from livestock during the dry season. However, farmers do not have the finance to buy fencing material.

6.2.5 Household perceptions of the trends in milk, draft power crop productivity over time

Households were asked about their perceptions of the trends in milk, draft power and crop productivity over time. Across all survey sites, at least 50 percent of the households perceive that milk, draft power and crop productivity has been declining over time (Figure 6.2). Of those households who perceive a decline in agricultural productivity over time, they were asked if they thought the decline in productivity was due to overgrazing. The results are presented in Table 6.9. Milk yields, and draft power output are the ones perceived to be declining due to overgrazing in Chiduku communal area in general and particularly in Matsika. Except in Chiduku Vidco, generally, the drop in crop productivity is not perceived to be due to overgrazing. Factors other than the degree of grazing seem to contribute towards the decline in crop yields e.g. rainfall and application of fertilizers.

Figure 6.2: Percentage households indicating that milk, draft power and crop productivity have decreased over the period 1980 to 1995 by survey site

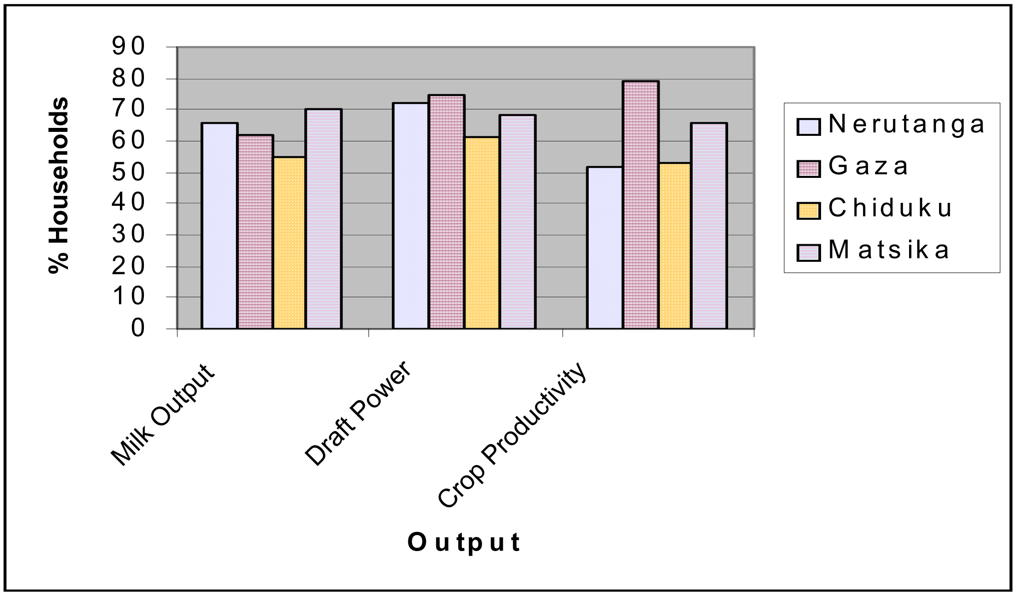


Table 6.9: Percentage households attributing the decline to milk, draft power and crop productivity to overgrazing by survey site

	BUHERA CA		CHIDUKU CA	
Decrease in productivity of:	Nerutanga	Gaza	Chiduku	Matsika
Milk	26	39	52	76
Draft power	18	46	61	77
Crop	3	10	32	16

6.2.6 Grazing time preference

Inter-temporal choices, decisions in which the timing of costs and benefits are spread over time, are important. With reference to grazing resource use in the communal areas, the question is how much grazing can a household access today and how much can it access in the future? In evaluating decisions that have temporally remote outcomes, economic agents have to make value comparisons between immediate and delayed consequences. Typically, this process relies on the technique of discounting. The discount rate used by economic agents to discount future consumption is the rate of time preference. Time preference refers to the value which people attribute to goods and services over time. In this study the aim is not to calculate the discount rates based on farmer responses but to analyze qualitatively the implicit time preferences of households with respect to grazing resource utilization.

Households were asked of their grazing time preference. Household responses to the time preference of grazing resource use were: to graze as much as possible today (a positive time preference), to graze minimally today to conserve grazing for future use (a negative time preference) and being indifferent. The results are shown in Figure 6.3. On average, households across all survey sites have a negative time preference i.e. household prefer to conserve grazing today than to overgraze. Table 6.10 shows that the negative time preference is irrespective of whether households have cattle or not. Based on these time preference results, grazing resources in the communal areas are not expected to be overgrazed. However, the results may be an indication of scarcity of grazing resources and households' response is in terms of the need to conserve grazing resources.

Figure 6.3: Percent distribution of household grazing time preference by survey site

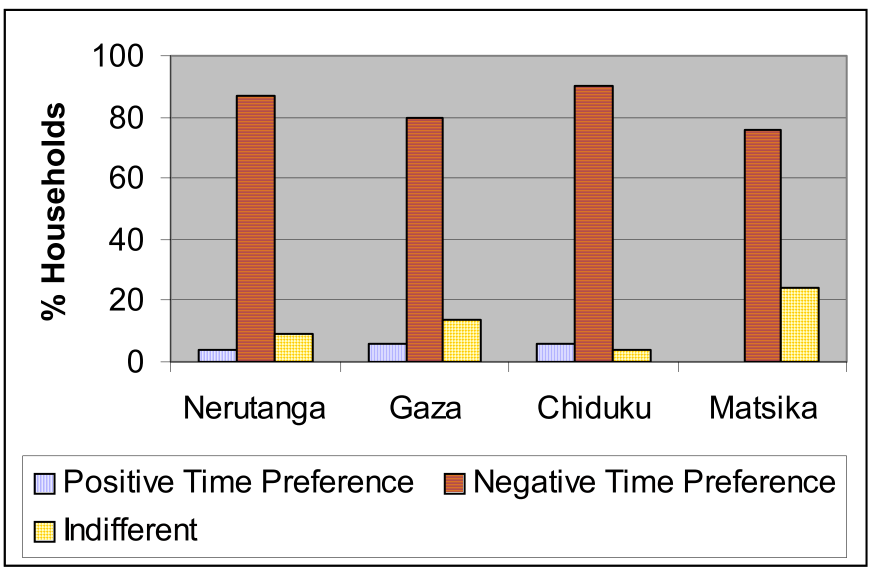


Table 6.10: Percent distribution of household grazing time preference by cattle herd size

	Cattle Ownership

Grazing time preference	0	1 – 4	5 - 10	> 10
- % HH with positive time preference	3.3	4.3	5.0	7.1
- % HH with negative time preference	80.1	88.7	85.0	78.6
- % HH Indifferent	16.6	7.0	10.0	14.2

Another explanation of these observed results is that households may have responded to the grazing time preference question in the "interest" or from a community perspective. However, when it comes to individual household decision making, the objective is to maximize the household returns or utility and not community returns/utility. This is so as long as there are no rules enforced that will result in the maximization of the community objective function.

6.3 An Institutional Analysis of Grazing Resource Use

As noted in Chapter 3, overgrazing is not the result of common property institutions, but the result of the inability of interdependent individuals to coordinate and enforce actions in situations of strategic interdependency. Common property arrangements are potentially equitable, economically efficient, and ecologically appropriate and sustainable (IFAD, 1995; Ostrom, et. al., 1994; Ostrom, 1990; Bromley and Cernea, 1989; Runge, 1986). In a common property regime (Swallow, 1990): (1) no single individual has exclusive rights to the use of the commons, (2) group members have secure expectations that they can gain access to future use of the resource, (3) there are functioning membership criteria, (4) there are communally defined guidelines for resource use, and (5) there is an enforcement mechanism for punishing deviant behavior. Swallow states that relatively few African rangeland situations satisfy all the conditions for common property, and that conditions (4) and (5) appear to be the most problematic. Lawry (1990) distinguishes between a "minimum" definition of common property and those arrangements needed to regulate resource use in a more intensive manner. A minimum definition is met where group membership rules are well defined and non-members are excluded access to common resources.

6.3.1 Design principles for common property resource management

In this section, a property rights framework by Ostrom (1990) is used to assess if grazing resources in the communal areas are open access or not. First, the design principles for a well-functioning common property resource are presented and then an analysis of the extent to which these principles are met in the context of communal grazing is made. If at least one of these principles is violated or is not met, then a common property resource is likely to slip into an open access resource. The design principles for enduring, self-governing common property resources include the following:

i. Clearly defined boundaries,
ii. Proportional equivalence between benefits and costs,
iii. Collective choice arrangements,
iv. Monitoring and enforcement,
v. Graduated Sanctions,
vi. Conflict-resolution mechanisms,
vii. Minimal recognition of rights to organize, and
viii. Nested enterprises.

6.3.1.1 Clearly defined boundaries

Defining the boundaries of the grazing resources and specifying those authorized to use them is the first step in organizing for collective action for the improved management of grazing resources. Without defining the boundaries of the rangelands and restricting access by outsiders, local herders face the risk that any benefits they produce by controlling their animal numbers and improvements in range productivity will be reaped by others who have not contributed to those efforts. At the worst, the actions of outsider herders may destroy the grazing resource itself.

6.3.1.2 Proportional equivalence between benefits and costs

Appropriation (i.e. use) rules restricting time, place, technology and/or quantity of grazing resources utilization are related to local conditions and to provision rules requiring labor, materials and/or money. Provision refers to the work necessary to ensure that the resource is available and maintained. These rules make it possible for individuals or households to have some certainty in the quantity of grazing they can appropriate or of the timing of its appropriation. Rules that specify the amount of resource harvested ensure that the benefits from use encourage expenditure of effort in resource provision.

6.3.1.3 Collective choice arrangements

If most individuals who are affected by the operational rules can participate in modifying the operational rules, they are better able to tailor their rules to local circumstances. This is because the individuals who directly interact with one another and with the physical environment can modify the rules over time so as to better fit them to the specific characteristics of their setting. It is important that the process of changing rules should involve low costs - otherwise it is expensive to design rules and hence it may be efficient to continue with open access institutions.

6.3.1.4 Monitoring and enforcement

To have long-enduring grazing resources, active investment in monitoring and sanctioning activities is apparent. For grazing resource institutions to be robust, monitoring and sanctioning need not necessarily be undertaken by external authorities but by the herders themselves. In this case herders spend time and effort to monitor and sanction each other's performances. Herders can create their own internal enforcement mechanisms to: (1) deter those who are tempted to break rules and thereby (2) assure quasi-voluntary compliers that others also comply. However, the normal presumption is that participants will not undertake mutual monitoring and enforcement because such actions involve relatively high personal costs and produce public goods available to everyone. Punishment is costly to the punisher, while the benefits from punishment are diffusely distributed over the members. If participants monitor each other, either the costs of monitoring are lower or the benefits to an individual are higher, or both, i.e. there has to be positive net benefits from monitoring to the individual. The costs of monitoring may be made low as a result of the rules in use i.e. if monitoring is a by-product of the individual's strong motivations to use the resource in question.

6.3.1.5 Graduated Sanctions

Appropriators who violate operational rules are likely to be assessed through graduated sanctions, i.e. sanctions that depend on the seriousness and context of the offense, by other appropriators or by officials accountable to the appropriators, or by both. In such a case, herders' perceptions of how others will behave are so balanced that they decide – at least most of the time – to conform to the operational rules. This can be described as contingent behaviour or quasi-voluntary compliance.

If someone who breaks the rules and is apprehended by a local monitor after having succumbed to the temptation to break rules will have three results: (1) it will stop the infraction from continuing and may return contraband harvest to others, (2) it will convey information to the offender that someone else in a similar situation is likely to be caught, thus increasing confidence in the level of quasi-voluntary compliance, and (3) a punishment in the form of a fine, plus loss of reputation for reliability, will be imposed. A large monetary fine may not be needed to return an occasional offender to the fold of those who are quasi-voluntary compliers with the rules. A large monetary fine imposed on a person facing an unusual problem may produce resentment and unwillingness to conform to the rules in the future. Graduated punishment ranging from insignificant fines all the way to banishment, may be far more effective than a major fine imposed on, for example, a first offender.

6.3.1.6 Conflict-resolution mechanisms

If individuals are going to follow rules over a long period of time, there must be some mechanisms for discussing and resolving what constitute an infraction. If some individuals are allowed to free-ride, some will feel cheated, and they could attempt to free-ride next time. If individuals who make honest mistakes or face personal problems that occasionally prevent them from following a rule do not have access to mechanisms that will allow them to make up for their lack of performance in an acceptable way, rules may come to be viewed as unfair, and conformance rates may decline. Thus, appropriators and their officials have to have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.

Although the presence of conflict- resolution mechanisms does not guarantee that appropriators will be able to maintain enduring institutions, it is difficult to imagine how any complex system of rules could be maintained over time without such mechanisms. Conflict resolution mechanisms may be informal and in cases where the potential for conflict over a very scarce resource is so high, well-developed court mechanisms may be put in place.

6.3.1.7 Minimal recognition of rights to organize

Institutions endure when the rights of appropriators to devise their own resource management systems are not challenged by external governmental authorities. Appropriators frequently devise their own rules without creating formal governmental jurisdictions for this purpose. Provided the external governmental officials give at least minimal recognition to the legitimacy of such (local) rules, local communities may be able to enforce the rules themselves. But if external governmental officials presume that only they have the authority to set the rules, then it will be very difficult for local appropriators to sustain a rule-governed CPR over the long run.

6.3.1.8 Nested enterprises

Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises. There is need to design rules at different levels of interaction e.g. local level, ward level, district level etc. Establishing rules at one level, without rules and an overseer at higher levels, will produce an incomplete system that may not endure in the long-run.

6.3.2 Institutional analysis results

The results of this chapter so far show that grazing resource utilization in the communal areas may be overgrazed. However, this does not necessarily mean that grazing resources use in the communal areas is open access. A summary of the rules governing grazing resource use in the survey areas is presented in Table 6.11. Most of the design principles for grazing resource management are met in Nerutanga. In all the survey sites the existence of graduated sanctions is associated with when cattle destroy crop fields and is not related to grazing management *per se*.

Except for Nerutanga, the results suggest that there may be no boundary rules, provision rules and monitoring of grazing resource use in the study sites (Table 6.12). There are also no rules concerning the number of cattle a household can keep. Monitoring to exclude other communities is weak if it is existent at all, except in Nerutanga.

Table 6.11: Presence of design principles for grazing resource management by survey site

Design Principle	Nerutanga	Gaza	Chiduku	Matsika
Clearly defined boundaries	✓	×	×	×
Proportional equivalence between benefits and costs	✓	×	×	×
Collective choice arrangements	✓	×	×	×
Monitoring and enforcement	✓	×	×	×
Graduated Sanctions	✓	✓	✓	✓
Conflict-resolution mechanisms	×	×	×	×
Minimal recognition of rights to organize	×	×	×	×
Nested enterprises	×	×	×	×

Key × Design principle do not exist ✓ Design principle exists

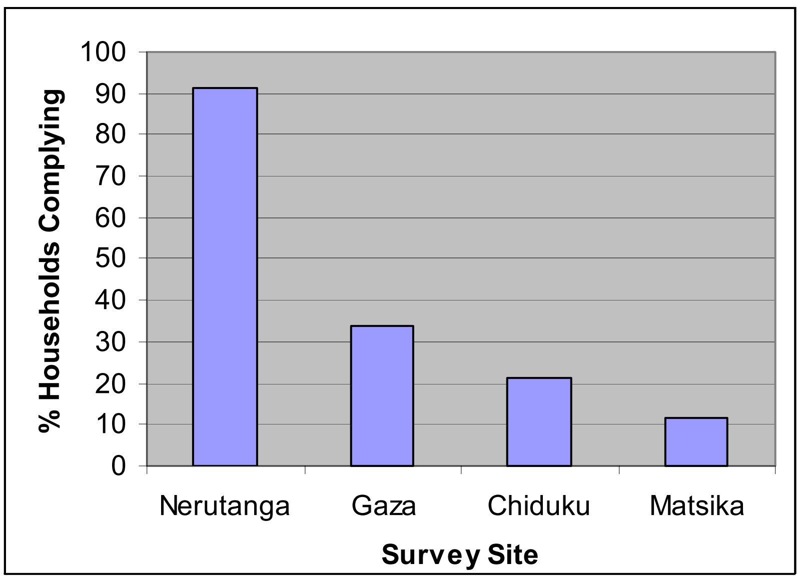
Table 6.12 Percentage households indicating the presence of rules governing grazing resource utilization by survey site

	BUHERA CA		CHIDUKU CA	
Rule	Nerutanga	Gaza-Chifamba	Chiduku	Matsika
Boundary	50.0	14.0	13.0	3.0
Provision	66.0	6.0	4.0	4.0
Monitoring	40.0	2.0	7.0	1.0

Across all survey sites, the boundary rules, though weak, are of two forms, which can be categorized into (i) within community boundary rules, and (ii) between communities boundary rules. Within the community, during the summer season, households are not allowed to graze near the cropped fields of other households, to prevent livestock from destroying crops. Across all the study areas, communities have an agreed rule that between certain dates during the rainy season and the harvesting season cattle must be herded and kept from damaging field crops. After this herders have the right to graze everywhere, including the fields belonging to other households. The dates after which cattle must be herded, and the date after which they are allowed to go free are decided by headmen on behalf of chiefs. During this period prosecution might occur for stray cattle damaging crops. Frequent conflicts occur, especially when leaders are reluctant to impose herding early enough to protect the crops of those who dry-plant or plant with the first rains.

Between the communities, households are not supposed to graze their livestock on grazing designated to other communities. So, there may be exclusion of other communities from utilizing local grazing resources. However, an analysis of the degree of compliance with inter-community boundary rules shows that except in Nerutanga, there seem to be weak inter-community boundary or exclusion rules. A high percentage of households graze their livestock in other communities grazing areas (Figure 6.4).

Figure 6.4: Percentage cattle owning households complying with inter-community boundary rules by survey site



In Nerutanga, households indicated there is monitoring of those who are supposed to use grazing resources. Also households indicated that there is some monitoring to ensure that only those who contribute to grazing improvement use the grazing resources.

These results seem to suggest that households know that there are boundaries for grazing resource use only that the boundary rules are not enforced and hence the high frequency of households grazing outside own communities. This indicates that grazing resource use in the communal areas is open access. However, given that within community rules of where to graze seem to be followed, rents from grazing resource use might not be completely dissipated.

In the study sites, like in all communal areas, Wards and Vidcos are considered to be the administrative units of land, even though the Ward/Vidco boundaries may change. The Wards/Vidcos are not necessarily natural or exclusive units of natural resource management, including grazing. Due to the large size of most of the Wards common property resource use tends to be confined to areas adjacent to the villages. Thus it is easier for the communities to identify with neighborhood rather than ward resources.

6.4 Summary

This chapter set to determine if grazing resources in the CA are overgrazed and/or open access. From an institutional analysis view point, the results seem to show that except for Nerutanga, in order of increasing seriousness, there might be overgrazing in Matsika, Gaza and Chiduku. The analysis of grazing pressure indices seem to show that Gaza and Chiduku are over-grazed. However, Nerutanga seems to be more overgrazed than Matsika. The major reasons for overgrazing in order of importance are: (1) there is little land for grazing; (2) households do not sell their cattle; (3) households from other communities graze on local grazing lands; and (4) low rainfall and/or huge fluctuations in rainfall. On average, households across all survey sites have a negative time preference i.e. household prefer to conserve grazing today than to overgraze. However, this result is an indication of scarcity of grazing resources and households' response is in terms of the need to conserve grazing resources.

Due to lack of inter-community boundary rules and the other design principles for grazing resource utilization, grazing resources in the CA are broadly open access. Thus, some of CA grazing resources appear to be both open access and overgrazed, hence the need to come up with policy instruments for grazing resource management.

Livestock grazing areas are frequently described as belonging to certain loosely defined communities. In general, it is the areas near the homes that coincide with the actual daily ranging patterns of herded livestock from the villages. However, the existence of such grazing areas does not mean that exclusive tenure is held over these pieces of land. Overlapping rights exist between neighboring Vidcos. Mechanisms do not exist for defining boundaries and exclusivity of use between them.

CHAPTER VII: DETERMINANTS OF HOUSEHOLD CHOICE OF ALTERNATIVE GRAZING MANAGEMENT POLICY OPTIONS

7.0 INTRODUCTION

As part of exploring the potential for using TGR for grazing resource management, it is necessary to assess the preference of the option *via a viz* other potential grazing management options and the status quo. It will be easier to implement TGR if there is support for the policy. Thus, the objective of this Chapter is to assess the factors affecting the likelihood of households choosing alternative grazing management policy options. The major hypothesis being tested in this Chapter is that farmers' choice of grazing management policy options is significantly affected by household characteristics.

Researchers and policy makers give considerable weight to farmers' opinions on public policy. Most published work in this area uses survey data, reporting the proportion of the sample population that supports a given policy initiative (Guveya and Chikandi, 1996; Jordan and Tweeten, 1987; Guither et al., 1984). Some analysts have reported the level of support for the policies by subgroups (Coughenour and Christenson, 1983). Others have focused on the simple correlation between policy preferences and individual socioeconomic variables (Edelman and Lasley, 1988; Lasley et.al., 1983; Padgitt and Lasley, 1983), and others have used the econometric approach (Orazem, et. al., 1989; King and Robison, 1981).

Following Orazem et. al., (1989) and King and Robison (1981), this chapter uses the econometric approach to determining the variables that shape farmers' preferences for alternative grazing management policies. The advantage of the regression approach is that one can determine the marginal effect of a given variable on the probability of support, holding all other factors constant. The econometric approach yields insights into a number of questions, which include: Are farmers' policy support opinions shaped by farmer socio-economic characteristics? How sensitive is farmer support for a given policy to changes in socio-economic circumstances? Can camps of support for individual farm policies be identified by farmer characteristics? Are these camps of support unique - implying that it would be difficult to build coalitions of individual camps-, or are they interrelated - implying that the camps would support the policies supported by other groups?

The chapter analyses the determinants of farmer opinion/choice of eight potential grazing management policies, in order of the increasing link between costs and benefits:

i. Status quo
ii. Grazing schemes,
iii. Community grazing management,
iv. Fodder production.
v. Taxation of all cattle,
vi. Taxation of cattle above four cattle,
vii. Tradable grazing rights, and
viii. Individualization of grazing.

Of the policies to be analyzed, policies v - vii can be described as market-based mechanisms for grazing resource management and the rest can be described as non-market-based mechanisms.

7.1 A Model of Farmer Preference of Grazing Policy

A behavioral model of a farmer's support of grazing resource policies is developed. Following from Edelman and Lasley (1988), it is reasonable to view farmers' responses to the opinion surveys on the several grazing policy options as votes on policy. Unlike most elections where voters can support only one option against another, a farmer can express support for more than one policy on an opinion survey. Thus, the behavioral model of policy preferences must allow the respondent to support more than one option at a time.

Assume n mutually exclusive policies that might be used in grazing resource management, G_1, G_2, ..., G_n. Each of these policies have an associated probability of implementation, P_1, P_2, ..., P_n such that $P_1 + P_2 + ... + P_n = 1$. The expected utility conditional upon the implementation of policy G_1, evaluated in period zero will be:

$$\in \left(\sum_{t=0}^{T} \delta^{t} U_{1t} \mid \varsigma_0 \right) = U^{1}(\varsigma_0), \qquad (7.1)$$

where $\in$ is the expectation operator, δ is the discount factor, $0 < \delta < 1$, U_{1t} is the utility under policy G_1 at time t, and (ζ_0) is the information set the farmer has upon which to base his/her expectations of future utility at time zero.

The expected present value of utility under all possible policies can be constructed as:

$$U^{0}(\zeta_0) = P_1 U^{1}(\zeta_0) + P_2 U^{2}(\zeta_0) + \ldots + P_n U^{n}(\zeta_0), \qquad (7.2)$$

so that the farmer's unconditional expected utility will be the weighted sum of the conditional expected utilities under each policy, with the probability of policy i's occurrence being the weight associated with $U^i(\zeta_0)$.

A farmer supports an individual grazing management policy when his/her expected utility under this particular policy significantly dominates his/her average expected utility, U^0 and will reject a policy if its expected utility is significantly less than U^0. Clearly a farmer can support more than one policy because more than one policy can have a higher expected utility than U^0. However, no farmer will support all policies because, by equation (7.2), it is impossible to have U^i larger than U^0 for all i.

A farmer's assessment of expected utility from various policies is undoubtedly subject to error. Therefore the difference between the conditional expected utility under policy i and the unconditional expected utility can be written as $U^i - U^0 = \underline{U}^i + \varepsilon^i$, where ε^i is an error term with mean zero and variance σ^i. The degree of uncertainty surrounding $\underline{U}^i$ rises as σ^i increases. If the farmer is risk averse, he/she will select critical values of $\underline{U}^i$ which will determine his/her attitudes towards policy i. Using μ_1^i and μ_2^i as these critical values, the farmer's decision regarding a given policy i can be summarized as (Orazem, et. al., 1989; King and Robison, 1981):

$$-\infty < U^i(\zeta_0) - U^0(\zeta_0) < \mu_1^i \Rightarrow \text{oppose policy i.}$$
$$\mu_2^i < U^i(\zeta_0) - U^0(\zeta_0) < +\infty \Rightarrow \text{support policy i.} \qquad (7.3)$$

To make (7.3) operational, the elements of ζ_0 – the farmer characteristics - must be established. One reason these characteristics may be correlated with expected utility from a given policy is that tastes or preferences for policies depend on the likelihood that utility or expected profits under various policy regimes will vary systematically across farmer characteristics. Assume that the function $U^i(\zeta_0)$ can be approximated by (Orazem, et. al., 1989):

$$U^i = \sum_{j=1}^{N} \beta_j^i X_j + e^i \qquad (7.4)$$

where X_j is one of n farmer characteristics, $ß_j^i$ is the effect of X_j on expected utility under grazing policy G_i, and e^i is the error term. If a variable Y^i is defined as an observed indicator of farmer support for policy G_i, the empirical approximation of (7.3) can be written as:

$$Y^i = 0 \text{ if } -\infty < \tau^i X + v^i < \mu_1^i,$$
$$Y^i = 1 \text{ if } \mu_2^i < \tau^i X + v^i < +\infty, \qquad (7.5)$$

where $\tau^i = ß^i - ß^0$ is a 1 x n vector of parameters, X is the n x 1 vector of elements in the information set, and $v^i = e^i - e^0$ is a vector of error terms. If v^i is distributed normally with mean zero and variance one, (7.5) is a probit model specification.

The estimates of τ^i will yield information on the impact of each household characteristic on expected utility under policy i relative to the characteristic's expected effect across all potential policies. A significantly positive parameter estimate implies that the corresponding characteristic receives a higher than average expected returns under policy i. Households that have large endowments of this characteristic will form a constituency in support of policy i. Conversely, a negative parameter estimate implies that the expected returns to the characteristic are lower than average under policy i, and households with large endowments of this characteristic form a constituency in opposition to the policy. An insignificant parameter estimate implies that the characteristic is not important in shaping the preference for policy i.

7.2 Empirical Model Estimation

For each of the alternative grazing policies, a probit regression model is estimated. In a probit model, the dependent variable is not continuous but is binary or dichotomous i.e. it takes on the values of 1 or zero. So if a grazing policy G_i is preferred, the dependent variable takes on the value 1, otherwise it is a zero.

The percent households who indicated preference for the alternative grazing policies are presented in Table 7.1. The means show that the most preferred grazing policy is the individualization of grazing (67 percent of the households) followed by grazing schemes and then tradable grazing rights. The least preferred option is fodder production and then the status quo. It is relatively easy to explain why the last two are the least preferred. With reference to the status quo, farmers realize and acknowledge that there has been deterioration in the state of their grazing resources. With respect to fodder production, three issues arise:

i. Given the little land available to the farmers, farmers cannot afford to grow fodder on their limited available land.
ii. Fodder production may be labor intensive in terms of land preparation and looking after the crop to prevent destruction by livestock. This labor might not be available in the household.
iii. There may be need to invest in fencing to reduce on the labor input for looking after the fodder. Most households do not have the cash to invest in fencing as may be evidenced by the lack of fencing of the crop fields.

Why households prefer the individualization of grazing (IOG) might arise from the following:

i. The piece of land allocated to the household is under the full control of the household, which then determines how it can be used for grazing.
ii. For non-cattle owners, ownership of such a piece of land may be a way of being assured of an income or some benefits in-kind year after year, since they can rent out that piece of grazing land.

iii. Since the piece of land, as indicated in the questionnaire, is given for free[21], then farmers as rational actors, do not mind having access to a free good.

Table 7.1: Description of Dependent Variables for Probit Model Estimation

Dependent Variable	Description	Measurement	Mean
STAT	Preferred grazing policy is the status quo	1 = yes 0 = otherwise	0.203
GS	Preferred grazing policy is grazing schemes	1 = yes 0 = otherwise	0.495
CGM	Preferred grazing policy is community grazing management	1 = yes 0 = otherwise	0.365
FP	Preferred grazing policy is fodder production	1 = yes 0 = otherwise	0.17
TXAL	Preferred grazing policy is taxing all cattle	1 = yes 0 = otherwise	0.283
TXG7	Preferred grazing policy is taxing cattle above 4	1 = yes 0 = otherwise	0.262
TGR	Preferred grazing policy is tradable grazing rights	1 = yes 0 = otherwise	0.433
IOG	Preferred grazing policy is the individualization of grazing	1 = yes 0 = otherwise	0.670

This policy preference outcome may be a direct outcome of the clear institutional failure to manage the commons in the communal areas hence the desire to individualize grazing ownership. However, the individualization of grazing does not necessarily result in the proper or sustainable management of the commons. It is not technically feasible to give individual plots to farmers as these will be too small to ensure adequate cattle feed for the households. Also, and more importantly, through individualization farmers will not be able to strategically graze their cattle on different grazing locations and patches during the different seasons of the year.

The grazing scheme (GS) option is the one that farmers are familiar with since it has been

[21] This assumption is made because land in the communal areas is not sold but is allocated for free.

implemented in some of the communal areas. One possible reason for the seemingly low percentage of farmers supporting this grazing policy is the expected high fencing costs associated with this policy. Before, most of the cash costs, especially the fencing costs were met by donors. Whilst the case for the individualization of grazing tend to point to farmers taking advantage of a situation where they can get access to land as a free good, the case of grazing schemes suggest that some farmers are willing to meet the costs of grazing. For this group of farmers, what seems to be an important factor is the exclusion of outsiders from accessing "their" grazing resources. As long as the users of the grazing resources are clearly defined and exclusion is enforced, some farmers are willing to invest in grazing resources in the form of grazing schemes. The analysis shows that from an equity view point, the taxation of all cattle may be undesirable. When all cattle owning households are taxed, poor households are discouraged from owning cattle, whilst those with large herds may not necessarily reduce their herd sizes because they have a low response to tax levels.

The following characteristics of tradable grazing rights as expressed to farmers during the interviews can explain why TGR are preferred by at least 40 percent of the survey households:

i. Grazing shares are given for free to households i.e. grand fathering, and
ii. The shares are distributed equally amongst cattle and non-cattle owners. In this case non-cattle owners benefit directly from selling their grazing rights to cattle owners, an aspect which is currently non-existent.

The characteristics of the TGR option that would result in low votes include the following:

i. That the grazing rights per household fluctuate over a given time period, and therefore there is no guaranteed income from the sale of grazing rights by non-cattle owners.
ii. That if the grazing quota for a particular specified time period is met, cattle without grazing rights are sold – unlike the IOG and GS options where there is no "compulsory de-stocking".

Table 7.2 presents a description of the model variables and their means. A correlation test among the explanatory variables was undertaken and there was no high correlation amongst the variables. The explanatory variables were regressed against each dichotomous grazing policy dependent variable. The probit estimates were obtained using SHAZAME. The results of the analysis are presented in Table 7.3.

Table 7.2: Explanatory Variables for Alternative Grazing Policies

Variable	Description	Measurement	Mean
WLTHRICH	Household wealth rank is rich	1 = yes; 0 = otherwise	0.11
WLTHMEDM	Household wealth rank is medium-rich	1 = yes; 0 = otherwise	0.37
WLTHPOOR	Household wealth rank is poor	1 = yes; 0 = otherwise	0.52
SEXMALE	Sex of household head (HHH) is male	1 = yes; 0 = otherwise	0.43
SEXDFMAL	Sex of household head (HHH) is *de facto* female	1 = yes; 0 = otherwise	0.34
SEXWIDOW	Sex of household head (HHH) is widow	1 = yes; 0 = otherwise	0.23
EDUCNONE	Education level of HHH is none	1 = yes; 0 = otherwise	0.16
EDUCPM	Education level of HHH is primary	1 = yes; 0 = otherwise	0.61
EDUCSC	Education level of HHH is secondary	1 = yes; 0 = otherwise	0.23
AGEHHH	Age of HHH	Age of household head (years)	52.08
FARMSIZE	Total HH farm size	Total hectares owned (ha)	1.90
NRCATLE	Number of cattle owned by HH	Number of cattle	2.22
GRAZING	Household is staying on grazing land	1 = yes; 0 = otherwise	0.27
NATREG2	Natural region is 2	1 = yes; 0 = otherwise	0.25
NATREG3	Natural region is 3	1 = yes; 0 = otherwise	0.5
NATREG4	Natural region is 4	1 = yes; 0 = otherwise	0.25
HHSIZE	Household size	Number of people in the household	4.19

Because probit coefficients are difficult to interpret (Briscoe et. al., 1990:123), the effects of the independent variables on the probability of supporting a given grazing management policy are presented in another way. For qualitative models, the estimated coefficients should be interpreted in the sense that they affect the probability that a certain event would occur (Misra et. al., 1991:224). For the continuous independent variables, the elasticities are a meaningful measure: the percentage change in the probability of supporting a given grazing management policy due to changes in the continuous variables. For discrete or dummy independent variables, elasticities are not meaningful because small changes in values are not possible. What is needed are marginal probabilities: the changes in the probability of supporting a given grazing management policy when the value of an independent variable changes from zero to one and vice versa. For the dummy dependent variables, the marginal probabilities are calculated by holding all the other dependent variables at their mean, except the dummy, and calculating the index Y^i when the dummy is one and when it is zero. The respective probabilities when the dummy is zero and when it is one are obtained from the standard normal distribution table. The difference in the probabilities when the dummy is zero and when it is one gives the marginal probability.

The maximum likelihood parameter estimates for the eight grazing management policies are accompanied by their corresponding elasticities (for continuous variables) and marginal probabilities (for discrete variables). The results indicate that it is easier to identify camps of support or opposition for three of the eight policy options: taxation of all cattle, fodder production, and the status quo. This is suggested by the higher number of significant coefficients for the various variables in the estimated equations. Sex and age of household head do not significantly affect support for grazing policies across all the eight policies. The rest of the variables are significant for at least one of the grazing policies.

The chi-square test of the null hypothesis that none of the variables in the model explain farmers' opinions on policy (i.e. all slope coefficients are zero) is rejected in all equations, except for the equation for taxing more than four cattle. This is because at least one of the explanatory variables significantly affects policy preference in seven of the eight equations.

Table 7.3: Maximum Likelihood Estimates of Probit Models of Household Preference of Alternative Grazing Management Policy Options

Variable	STAT	GS	CGM	FP	TXAL	TXG4	TGR	IOG
WLTHRICH	0.125[a]	-0.530**	-0.026	0.214	0.417*	-0.222	0.174	0.00001
	(0.43)[b] [0.03][c]	(-2.15) [0.180]	(-0.107) [-0.01]	(0.78) [0.06]	(1.67) [0.15]	(-0.81) [-0.07]	(0.71) [0.07]	(0.00) [0.0001]
WLTHMEDM	-0.187	0.151	0.039	0.028	0.126	-0.001	-0.023	-0.096
	(-1.04) [-0.04]	(1.04) [0.06]	(0.26) [0.01]	(0.15) [0.01]	(0.80) [0.04]	(-0.01) [0.0001]	(-0.16) [-0.01]	(-0.65) [-0.03]
SEXMALE	-0.303	-0.127	0.169	-0.217	0.024	0.223	-0.230	0.188
	(-1.37) [-0.01]	(-0.71) [-0.05]	(0.92) [0.06]	(-0.99) [-0.06]	(0.13) [0.01]	(1.17) [0.08]	(-1.27) [-0.09]	(1.01) [0.06]
SEXDFMAL	-0.034	0.112	0.134	-0.190	-0.148	-0.051	-0.228	0.209
	(-0.14) [-0.01]	(0.55) [0.04]	(0.65) [0.05]	(-0.77) [-0.05]	(-0.67) [-0.05]	(-0.24) [-0.02]	(-1.13) [-0.09]	(0.996) [0.07]
EDUCPM	-0.100	0.061	0.246	-0.395*	-0.140	0.171	-0.020	0.121
	(-0.46) [-0.02]	(0.35) [0.02]	(1.33) [0.09]	(-1.83) -0.11]	(-0.72) [-0.05]	(0.87) [0.05]	(-0.11) [-0.01]	(0.65) [0.04]
EDUCSC	0.300	-0.129	0.246	-0.157	0.084	-0.061	-0.123	-0.194
	(1.07) [0.07]	(-0.55) [-0.05]	(1.02) [0.09]	(0.57) [-0.04]	(0.34) [0.03]	(-0.23) [-0.02]	(-0.52) [-0.05]	(-0.80) [-0.07]
AGEHHH	-0.002	0.002	0.002	-0.008	0.002	0.0002	-0.004	0.003
	(-0.38) [-0.19]	(0.34) [0.08]	(0.28) [0.08]	(-1.19) [-0.06]	(0.43) [0.16]	(0.03) [0.01]	(-0.74) [-0.19]	(0.08) [0.06]
FARMSIZE	0.050**	0.008	0.026	-0.042	0.007	-0.027	0.002	-0.033
	(2.27) [0.35]	(0.41) [0.03]	(1.30) [0.13]	(-1.62) [-0.31]	(0.33) [0.04]	(-1.19) [-0.16]	(0.12) [0.01]	(-1.64) [-0.08]
NRCATLE	-0.043	0.021	-0.013	0.027	0.033*	-0.016	-0.056**	0.052**
	(-1.44) [-0.14]	(1.08) [0.04]	(-0.66) [-0.03]	(1.20) [0.09]	(1.68) [0.09]	(-0.75) [-0.05]	(-2.49) [-0.11]	(2.12) [0.62]
GRAZING	0.316*	-0.217	0.059	0.198	0.267*	-0.055	-0.096	-0.223
	(1.88) [0.08]	(-1.44) [-0.09]	(0.39) [0.02]	(1.13) [0.05]	(1.66) [0.09]	(-0.34) [0.02]	(-0.64) [-0.04]	(-1.45) [-0.08]
NATREG3	-0.897***	0.106	0.397**	-0.385**	0.768***	0.233	-0.233	0.206
	(-4.65) [-0.21]	(0.65) [0.04]	(2.35) [0.14]	(-2.08) [-0.10]	(4.09) [0.24]	(1.30) [0.08]	(-1.45) [-0.08]	(1.24) [0.07]
NATREG4	-0.262	-0.170	0.283	-0.525	0.368*	0.276	-0.478***	0.197
	(-1.34) [-0.05]	(-0.93) [-0.07]	(1.49) [0.11]	(-2.42) [-0.12]	(1.75) [0.12]	(1.37) [0.10]	(-2.58) [-0.18]	(1.05) [0.07]
HHSIZE	0.033	0.020	0.031	0.112***	-0.015	-0.014	-0.004	-0.068**
	(0.90) [0.20]	(0.70) [0.07]	(1.05) [0.13]	(3.22) [0.72]	(-0.48) [-0.08]	(-0.44) [-0.07]	(-0.14) [-0.02]	(-2.28) [-0.15]
Constant	-0.479	-0.225	-1.274***	-0.279	-1.317***	-0.758*	0.621	0.396
	(-0.96)	(-0.53)	(-2.93)	(-0.55)	(-2.84)	(-1.68)	(1.46)	(0.91)
Log-Likelihood	-175.19	-267.66	-255.46	-166.44	-223.5	-224.96	-263.95	-243.26
Chi-Square (13)	52.71***	19.13*	14.08	27.84**	29.24***	10.62	19.30*	20.82*
McFadden R-Square	0.131	0.034	0.027	0.076	0.061	0.023	0.035	0.041
Correct predictions (%)	80.50	58.75	64.25	83.25	72.75	73.75	56.25	65.75

[a] Coefficient [b] t-value [c] elasticity or marginal probability

* Significant at the 10 % level ** Significant at the 5 percent level *** Significant at the 1 percent level

For a measure of goodness of fit, there are problems with the use of the conventional R^2-type measures when the dependent variable is binary (Greene, 1990:682; Pindyck and Rubifeld, 1991:268; Baltagi, 1998:342). A number of proposals have been made for defining a measure analogous to R^2 in a conventional regression model. One suggestion, which is used here, is the McFadden R^2. If all of the slope coefficients are zero, the McFadden R^2 equals zero. Using the McFadden R^2, the results show that the hypothesis of zero slope for all equations is rejected. Another measure of goodness of fit is the percentage correct predictions. The percentage correct predictions range from 56 percent for TGRs and 83 percent for fodder production, indicating high goodness of fit. Again, the hypothesis of zero slope for all equations is rejected.

Elasticities are indicators of the sensitivity of support to changes in farmer characteristics. The results in Table 7.3 show that farmer opinion or choice of grazing policies are fairly stable. No elasticities or marginal probabilities are greater than one. For the status quo, only two elasticities exceed 0.20 in absolute value. The implication is that only dramatic changes in the socio-economic circumstances or farmer characteristics will alter the support or non-support for continuing the current grazing practice. However, small increases in farm size will strengthen the support for the status quo. The non-support for fodder production is highly sensitive to household size and farm size. The support for the individualization of grazing is highly sensitive to the number of cattle kept. The support for the taxation of all cattle is highly sensitive to agro-ecological region. Preference for the rest of the policy alternatives is not sensitive to household characteristics as shown by the low absolute elasticity and marginal probability values.

7.2.1 Tradable grazing rights

The factors that significantly affect the support for tradable grazing rights (TGR) are the number of cattle owned and agro-ecological region. Households with large cattle herds are more likely to oppose TGR. Conversely, households with small cattle herds or have no cattle at all are more likely to support TGR. A 10 percent increase in the number of cattle owned would reduce the probability of support by 1.1 percent. The opposition to TGR by large stock owners results from the fear of de-stocking which might occur if demand for grazing rights exceeds the carrying capacity of the veld. Households in NR IV are more likely to oppose tradable grazing rights than households in NR II. A 10 percent increase in the proportion of farmers in NR IV would decrease the probability of support for TGR by 1.8 percent.

Sex of household head male and female and the location variable for NR III have negative coefficients approaching significant levels (i.e. their t-values are greater than 1). An increase in the proportion of male and female headed households, versus widowed households, and households in NR III is likely to result in a decrease in the probability of support for TGR.

7.2.2 Individualization of grazing

The factors that significantly affect the support for the individualization of grazing (IOG) are the number of cattle owned and household size. As household size increases, support for individualization of grazing decreases. A 10 percent increase in household size would result in a 1.5 percent decrease in the probability of support for the IOG. As expected *a priori*, households with more cattle support IOG as they could have more household land to graze their cattle. A 10 percent increase in cattle herd size would increase the probability of support for IOG by 6.2 percent.

Sex of household head male and the location variables NR III and NR IV have positive coefficients approaching significance whilst farm size has a negative coefficient approaching significance. Increasing the proportion of male-headed households and households in NR III and NR IV would increase the support for IOG. Households with large farms oppose IOG or conversely households with small farms support IOG. On average, a 10 percent increase in farm size is likely to result in a 0.8 percent decrease in the probability of support for IOG. As expected *a priori*, households with small land holdings see the opportunity of expanding their land ownership by supporting the IOG. Conversely, those households with large pieces of land would derive little marginal utility from earning an extra acre of land, thus the low support for IOG.

7.2.3 Grazing schemes

The only variable that is significant is household wealth status. Rich households have a higher and significant probability of opposing grazing schemes than poor households. The coefficient for medium rich households is positive and approaches standard significant levels. This variable tends to increase the probability of support for grazing schemes. A 10 percent increase in the proportion of rich households would result in a 1.8 percent decrease in the probability of support for grazing schemes. One possible reason why the poor have a higher probability of supporting the formation of grazing schemes is that they see the schemes as a mechanism for maintaining the commons where they can gather foods and other communally held resources. Additionally, community level enclosure made possible by establishing grazing schemes may present a lower cost to the poor households than if individual enclosure of grazing was allowed.

The variable for households staying in areas designated for grazing have a negative coefficient approaching significance levels. Households residing in areas designated for grazing, as expected *a priori*, would tend to oppose grazing schemes. If grazing schemes were to be established, these households would be required to relocate to new settlements, hence the non-support of grazing schemes.

7.2.4 Taxation of all cattle

The taxation of all cattle is significantly affected by agro-ecological region, the number of cattle owned, residence in areas designated for grazing, and household wealth status. Households in NRs III and IV tend to support taxation of all cattle than households in NR II. A 10 percent increase in the proportion of households in NR III and NR IV would increase the probability of support for taxing all cattle by 2.4 and 1.2 percent respectively. Contrary to *a priori* expectations, households with more cattle are significantly more likely to support taxation of all cattle. A 10 percent increase in the cattle herd size would increase the probability of support by 0.9 percent. The reason for such type of behavior is not clear and future research is needed to explore this further.

Rich households are significantly more likely to support the taxation of all cattle than poor households. The probability that medium-rich households support taxing all cattle owners is not significantly different from that of poor households. A 10 percent increase in the proportion of rich households would increase the probability of support for taxing all cattle owners by 1.5 percent.

An interesting result is that households residing in areas designated for grazing support the taxation of all cattle. The possible interpretation is that these households are aware that with taxation of all cattle, some of the households may reduce their cattle herds, hence ensuring the availability of land for those residing in the grazing areas. This only holds as long as only the tax is introduced and no by-laws are passed to evict all those residing in grazing areas.

7.2.5 Taxation of more than four cattle only

The most striking result of the equation explaining support for taxing only those households with more than four cattle is that there is no variable that significantly affects the non-support or support of this policy at the 10% significance level. The test of hypothesis that the coefficients are jointly equal to zero cannot be rejected at the 10 percent level. However there are a number of variables whose coefficients approach standard significant levels: sex of household head, agro-ecological region, and farm size. Male headed households have a higher probability of supporting the taxation of more than four cattle than widow headed households. Households in NR III have a higher probability of supporting this policy than households in NR II. Households with large farm sizes are likely to oppose the taxation of more than four cattle than households with smaller farm sizes.

7.2.6 Community grazing management

The only significant variable is the location variable, NR III. Households in NR III are more likely to support community-grazing management (CGM) than households in NR II. A 10 percent increase in the proportion of households in NR III would increase the probability of support for CGM by 1.4 percent. The probability that households in NR IV support CGM is not significantly different from that for NR II.

7.2.7 Fodder production

The factors that significantly affect the non-support of fodder production are the education level of household head, agro-ecological region, and household size. Households whose heads attained primary education tend to oppose fodder production compared to households whose heads did not attend school. Increasing the proportion of households whose heads have attained primary education by 10 percent would reduce the probability of support for fodder production by 1.1 percent. The probability of support for fodder production is not significantly different between households whose heads did not attend school and those whose heads attained secondary education.

Household size is highly sensitive to the probability of support for fodder production. A 10 percent increase in household size would increase support for fodder production by 7.2 percent. This result is as expected *a priori*. As household size increases, more labour is available to the produce fodder.

Households in NRs III and IV have a higher probability of opposing fodder production when compared to households in NR II. A 10 percent increase in the proportion of households in NRs III and IV would reduce the probability of support for fodder production by 1.0 and 1.2 percent respectively. The low probability of support for fodder production in low rainfall areas is as expected *a priori*, unless drought resistant fodder is identified to supplement the pastures.

The coefficients for the number of cattle owned, residence onto areas designated for grazing and age of household head approach significance. The probability of support for fodder production increases as the proportion of households residing in areas designated for grazing and the number of cattle owned increase. The latter is as expected *a priori*. As the age of household increases the probability of support for fodder production decreases.

7.2.8 Current grazing practice

The factors that significantly affect the support or non-support of the current grazing practice are farm size, residence in areas designated for grazing, and agro-ecological region. As farm size increases, the probability of support for the current grazing practice increases. A 10 percent increase in farm size increases the probability of support by 3.5 percent. Households with large holdings may be able to supplement grazing from their own land. Thus, the need to change the status quo is not pressing for these households.

The probability of support for the current grazing practice is higher for households residing in areas designated for grazing than for households not staying in areas designated for grazing. A 10 percent increase in the proportion of households residing in areas designated for grazing increase the probability of support for the current practice by 0.8 percent. As expected *a priori*, households residing in areas designated for grazing would support the status quo since they are not willing to be moved from their current settlements to other settlements. This result is consistent with the results for the equation for the individualization of grazing (Section 7.2.2), grazing schemes (Section 7.2.3), and the taxation of all cattle (Section 7.2.4).

Households in NR III have a significantly lower probability of support for the current practice than households in NR II. The coefficient for NR IV is negative and is almost significant. A 10 percent increase in the proportion of households in NR III would decrease the support for the status quo by 2.1 percent. The non-support of the status quo in low rainfall areas may be due to the perceived high degree of overgrazing in these areas that is exacerbated with frequent droughts.

The coefficients for medium-rich households, household heads who attained secondary education, the number of cattle owned and residence in areas designated for grazing approach significance. Medium-rich households are likely to oppose the status quo than the poor households whilst households whose heads attained secondary school are likely to support the status quo than households whose heads did not attend school. As the number of cattle owned increase, the probability of support for the status quo decreases.

7.3 A Test of Uniqueness of Grazing Policy Preferences

The previous section describes what type of farmers favor or do not favour any of the eight grazing policies. The results indicate identifiable camps of support for and against these policies. This section tests whether these camps are in fact significantly distinct. It is useful to know whether constituencies opposed to the current scenario will favor any alternative to the current practice or if opposition to the existing practice is fragmented among groups favoring several alternatives. If these policies have unique, identifiable camps of support and opposition, then a farmer with a high probability of support for one policy would have a low probability of support for any of the other alternative policies. If there is no systematic relationship between the probability of support for one policy relative to another or if there is a positive correlation between the probabilities of support of any two policies, then unique camps of support do not exist. This means a specification for equation (7.5) to include as additional regressors the predicted probabilities that the household supports the other seven policies. For any policy i, we would specify (Orazem, et. al., 1989):

$$Y^i = 0 \text{ if } -\infty < \tau^i X + \Sigma_{j\neq i}\, \delta_{ij}{*}Pr(G^j{=}2) + v^i < \mu_1{}^i,$$
$$Y^i = 1 \text{ if } \mu_2{}^i < \tau^i X + \Sigma_{j\neq i}\, \delta_{ij}{*}Pr(G^j{=}2) + v^i < +\infty, \qquad (7.6)$$

Where $Pr(G^j{=}2)$ is the probability that the individual household would support policy j , and δ_{ij} is the effect of the probability of supporting policy j on the probability of supporting policy i. If δ_{ij} is positive, then households who expect to benefit from policy j also expect to benefit from policy i. If δ_{ij} is negative, then households who expect to benefit from policy j expect to lose from policy i. If δ_{ij} is small numerically and statistically insignificant, then there is no systematic relationship between support for policy j and support for policy i.

The predicted probabilities of support for alternative policies were added to the original probit specification. Only the results that show the relationship between the alternative policies are presented in Table 7.4. The results for the farmer characteristics are not reported here. Based on the chi-square test, for all the equations except the one for taxing more than four cattle, we reject

Table 7.4: Maximum Likelihood Estimates of the Impact of Supporting Alternative Grazing Policies on the Probability of Supporting a Given Grazing Policy

Predicted Support for:	**Grazing Policy Option**							
	Tradable Grazing Rights	Taxing only more than four cattle	Community Management	Fodder Production	Status Quo	Individualization of Grazing	Grazing Schemes	Taxing all cattle
Tradable Grazing Rights		-1.924 (-0.720) [-1.05]	6.6941* (1.934) [3.01]	-1.398 (-0.588) [-0.95]	-4.690 (-0.971) [-3.06]	-0.662 (-0.298) [-0.15]	7.0597* (1.835) [2.46]	-2705 (-1.273) [-1.44]
Individualization of Grazing	-3401 (0.786) [-2.08]	-2.494 (-0.527) [-2.11]	2.627 (0.610) [1.83]	-2.311 (-0.483) [-2.42]	5.327 (0.797) [5.38]		5.366 (1.244) [2.89]	-2.105 (-0.446) [-1.73]
Grazing Schemes	21.949* (1.739) [9.95]	-2.305 (-0747) [-1.44]	-1.940 (-0.820) [-1.00]	-1.742 (-0.486) [-1.35]	-3.237 (-0.782) [-2.42]	1.729 (0.660) [0.46]		-2.218 (-0.766) [-1.35]
Taxing all cattle	0.302 (0.643) [0.09]	0.292 (0.605) [0.11]	-0.044 (-0.089) [-0.01]	-1.186* (-1.769) [-0.58]	0.198 (0.410) [0.09]	-0.0006 (-0.001) [0.00]	0.376 (0.817) [0.09]	
Taxing only more than four cattle	-9.887* (-1.712) [-2.40]		2.892 (0.969) [0.80]	4.015 (0.904) [1.66]	7.845* (1.703) [3.13]	-8.878* (-1.604) [-1.263]	-1.221 (-0.612) [-0.26]	-0.396 (-0.191) [-0.13]
Community Management	0.924 (0.220) [0.31]	-2.777 (-0.609) [-1.28]		1.705 (0.354) [0.97]	5.489 (1.052) [3.01]	0.833 (0.190) [0.16]	-2.290 (-0.516) [-0.67]	-0.674 (-0.165) [-0.30]
Fodder Production	0.836 (1.419) [0.51]	0.336 (0.554) [0.008]	-1.080* (-1.659) [-0.21]		0.452 (0.642) [0.13]	0.832 (1.199) [0.08]	-1.098* (-1.741) [-0.167]	-0.550 (-0.872) [-0.13]
Log-Likelihood	-254.50	-223.39	-248.16	-163.10	-169.84	-238.58	-260.16	-221.21
Chi-Square (13)	38.20***	13.75	28.67*	38.52***	63.39***	30.18**	34.16***	33.82***
McFadden R-Square	0.070	0.030	0.055	0.106	0.157	0.059	0.062	0.071
Percent correct predictions	58.5	73.8	65.8	83.5	81.5	66.5	61.5	73.5

[a] Coefficient [b] t-value [c] elasticity of marginal probability

* Significant at the 10 % level ** Significant at the 5 percent level *** Significant at the 1 percent level

the hypothesis that all the slope coefficients are zero. A similar result is obtained based on the McFadden R^2. Based on the percentage correct predictions all the equations have high goodness of fit ranging from 73.8 to 83.5 percent. Overall, the results for test of uniqueness for support of grazing management policies shows that there are clearly unique camps of support for fodder production and the individualization of grazing.

Increasing the predicted probability of support for IOG and community grazing management (CGM) does not significantly affect the probability of support of any of the alternative policies. Increasing the predicted probability of support for tradable grazing rights (TGR) significantly increases the probability of support for grazing schemes and community management. A 10 percent increase in the predicted support for TGR would result in a 24 percent and 30 percent increase in the probability of support for grazing schemes and community grazing management respectively.

There is a significant and positive impact of the predicted support for grazing schemes on the support for TGR. A 10 percent increase in the predicted support for grazing schemes results in a 99 percent increase in the probability of support for TGR. The co-support of these two grazing management policies may be attributed to the perceived high degree of overgrazing in the majority of survey sites and the policies are perceived as the solution to the overgrazing problem.

Increasing the predicted support for taxing all cattle by 10 percent significantly decreases the probability of support for fodder production by 5.8 percent. Increasing the predicted probability of support for taxing more than four cattle decrease the probability of support for TGR and individualization of grazing and increases the support for the current grazing practice. A 10 percent increase in the predicted support for taxation of more than four cattle decrease the probability of support for TGR and the individualization of grazing by 24 and 13 percent respectively. A 10 percent increase in the predicted support for taxing more than four cattle increases the probability of support for current grazing practices by 31 percent.

Increasing the predicted probability of support for fodder production decreases the probability of support for grazing schemes and community grazing management. A 10 percent increase in the predicted probability of support for fodder production, decrease the probability of support for grazing schemes and community grazing management by 1.6 and 2.1 percent respectively.

7.4 Summary

Based on the household ranking of preference of the alternative grazing management policies, the most preferred grazing policy is the individualization of grazing followed by grazing schemes and then tradable grazing rights. The least preferred options are fodder production and then the status quo. Fodder production is the least preferred because of the limited availability of land; fodder production is likely to labor intensive and this labor might not be available in the household, especially with the prevalence of HIV & AIDS. Most households may not have the cash to invest in fencing to protect the fodder crop as evidenced by the lack of fencing even for field crops. The status quo is not preferred because of the perceived overgrazing under the current grazing management system.

That the individualization of grazing (IOG) is the most preferred may be a direct outcome of the clear institutional failure to manage the commons in the communal areas. However, it is not technically feasible to give individual plots to farmers as these will be too small to ensure adequate feed for the household cattle, and farmers will not be able to strategically graze their cattle on different grazing locations and patches during the different seasons of the year.

The probit results indicate the following. It is easier to identify camps of support or opposition for three of the eight policy options: taxation of all cattle, the status quo, and fodder production. The wealth status of household, the number of cattle owned, agro-ecological region and residence in areas designated for grazing positively and significantly influence the probability of support for the taxation of all cattle. There are no significant variables for opposing the taxation of all cattle. There are no variables that significantly affect the probability of support for the taxation of more than four cattle.

The results show that farmers' opinions on grazing policies are fairly stable. No elasticities or marginal probabilities are greater than one. The implication is that only dramatic changes in the socio-economic circumstances or farmer characteristics will alter the support or non-support for the different grazing policies. The test for uniqueness of camps for grazing policies suggests that there is no strong opposition against the current grazing management practice. However, (i) there are unique camps of support for fodder production and the individualization of grazing, and (ii) farmers who tend to support TGR also tend to support the implementation of grazing schemes and vice versa.

TGR can be compared to other policies where the number of cattle significantly affects the choice of grazing policy i.e. IOG and the taxation of all cattle. Whilst households with large cattle herds support the latter two policies, it is only TGR that is supported by those with smaller herds or no cattle at all. Since the percentage of non-cattle owners and those with small herds is high in all communal areas, the support for TGR, as indicated by the results, is likely to be high from this category of farmers. However, they are likely to face implementation problems from those with large cattle herds and those in low rainfall areas. A possible reason for non-support is that large herd owners may be required to de-stock if they fail to secure grazing rights. Those with smaller cattle herds or who have no cattle at all support TGR because they could get some income from the sale of grazing rights. The low support in low rainfall areas may be arising from two factors: (i) the low grazing pressure and human population densities in these areas when compared to NR II so that the status quo is viewed as less of a problem, and (ii) due to the poor rainfall, the chances of destocking with TGR is high in low rainfall areas, hence the low support.

The results have important implications for the current land reform program. One of the key results is that households in relatively high rainfall areas have a higher probability of support for TGR than those in low rainfall areas. In the current resettlement program a substantial number of farmers are moving from low rainfall areas to relatively high rainfall areas. Hence the support for TGR is likely to increase. This support is enhanced by the fact that the majority of these households have small herds or no cattle at all.

For areas of further research, it would be interesting to do a comparison of household preference of alternative policies at different points in time, allowing an examination of the power of the model to forecast future support for grazing policies. A panel study would be useful in examining the persistence of an individual household's preference under different economic environments. An assessment is required of the preference for TGR if the initial allocation of grazing rights were to be held over a long time period, say 99 years. Further work is required to assess why large herd owners support the taxation of all cattle.

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CHAPTER VIII: ESTIMATING THE POTENTIAL IMPACTS OF IMPLEMENTING TRADABLE GRAZING RIGHTS ON CROP AND LIVESTOCK PRODUCTIVITY

8.0 INTRODUCTION

The objective of this Chapter is therefore to assess household attitudes towards use of tradable grazing rights for grazing resource control through assessing: household willingness to pay (WTP) and willingness to accept (WTA) for grazing rights and the preferred mode of payment for grazing rights. The hypotheses being tested in this Chapter are:

(i) Communal area households with large cattle herds are willingness to pay for grazing rights,

(ii) Communal area households with small cattle herds or without cattle are willing to accept payment for grazing rights, and

(iii) The preferred mode of payment for grazing rights is similar between potential buyers and sellers of grazing rights.

Given the objective and hypotheses above, the purpose of this chapter is two-fold. Firstly, an analysis is made of the households' potential response to the implementation of tradable grazing rights (TGR). If TGR as a grazing management policy is to be implemented, it is necessary to analyze how households are likely to respond to this policy. If household attitudes are positive, then the implementation is likely to be more efficient than if household attitudes are negative.

Households' attitudes towards TGR are assessed through household willingness to pay (WTP) and willingness to accept (WTA) for TGR (Section 8.1) and the preferred mode of payment for TGR (Section 8.2). With the introduction of the TGR policy, a household would reduce its herd size if the expected utility of keeping a given herd size is low or negative. If the household derives more utility from keeping the large herd, then the household would be WTP for TGR and keep its large herd.

Currently, there is no grazing market in the communal areas. An analysis of both WTP and WTA for grazing rights would enable the assessment of the potential for creating a market for grazing in the communal areas of Zimbabwe. If those with "large" cattle herds are willing to pay little or nothing at all for grazing, then they are considered free riders. Conversely, an analysis of household WTA for TGR would enable the assessment of whether households are willing to be paid for providing grazing services. If households are willing to be paid for providing grazing services, then an analysis of the preferred mode of payment for grazing rights is important when designing the intervention strategy for TGR.

Secondly, based on the maximum willingness to pay (MWTP) and minimum willingness to accept (MWTA) for grazing rights, the chapter estimates potential demand and supply functions for grazing rights (Section 8.3). The derived demand and supply functions are used to estimate the potential equilibrium prices for grazing rights per survey site. Based on the derived demand functions for grazing rights, the potential unconstrained impact of TGR on the number cattle kept, cattle herd performance parameters, plowing rates, maize yields and milk yields are modeled. The models developed here link the demand functions for grazing rights to the production functions for cattle herd performance parameters, plowing rates, maize yields and milk yields (Section 8.4).

8.1 Testing for Biases in Household WTP and WTA for Tradable Grazing Rights

Households were asked of their WTP or WTP for grazing rights to assess household attitude towards TGR. The WTP and WTA values were derived as nominal payments (i.e. absolute non-referenced values. Before analyzing household WTP or WTA for grazing rights, this section will commence by assessing some of the biases that are encountered in WTP and WTA analyses. These are starting point and vehicle biases (Griffin, et. al., 1995; Seip and Strand, 1992; Whittington, et. al., 1990; Mitchell and Carson, 1989; Cummings, et. al., 1986). Types of biases that are encountered in valuation studies that are not analyzed here are the strategic bias or opening statement bias, hypothetical bias, information bias and valuation under ambivalence[22] (Ready et. al., 1995).

Hypothetical bias may arise for two reasons. First, the respondent may not understand or correctly perceive the characteristics of the good being described by the interviewer. Secondly, individuals may not take the valuation questions seriously and simply respond by giving whatever answer comes to their mind. Where this type of bias occurs, bids will be randomly distributed and not systematically related to household characteristics.

Strategic bias results from conscious attempts by individuals to influence their payment obligation or the level of provision of an environmental good through their stated valuations. Strategic bias arises from the efforts by respondents to:

i. "free ride", i.e. to reduce their payment obligations by stating low values, and
ii. influence the level of provision of an environmental good by stating artificially high or low figures.

Two types of information bias have been discussed in the literature. One refers to the effect of providing information on values and costs. If the information on values and costs is provided during interviews, it would appear to lead to bias through a kind of indicative effect akin to that leading to starting point bias. The second type of information bias result from changes in the information provided to individuals about the environmental good itself. There is evidence that individuals' bids can be changed in systematic ways by changes in the description of the environmental good (Hoevenagel and Van der Linden, 1993; Bergstrom, et. al., 1990; Boyle, 1989; Samples, et. al., 1986).

8.1.1Testing for starting point bias

Starting point bias occurs when the initial bidding price affect an individual's final WTP (Freeman, 1986; Cummings et al., 1986; Mitchell and Carson, 1989). In soliciting a respondent's WTP or WTA, using the bidding game format, a respondent who is unsure of an appropriate

[22] Ambivalence occurs when an individual is forced to make difficult trade-offs between competing objectives. For example, in a dichotomous choice contingent valuation survey, ambivalence can occur when a respondent

answer and wants to please the interviewer may interpret the initial price as a clue to the correct bid.

Table 8.1: Testing for starting point bias for WTP for grazing rights by Survey Site

Starting Point Bid (USD)	Nerutanga	Gaza	Chiduku	Matsika
	Mean Maximum Willingness To Pay (USD)			
0.91	0.40	0.26	0.20	0.17
1.83	0.18	0.37	0.19	0.74
2.74	0.10	0.05	0.57	0.16
3.65	0.39	0.03	1.70	0.78
4.56	0.00	0.10	0.07	0.11
5.48	1.01	0.04	1.67	0.40
Overall Mean	0.29	0.12	0.86	0.43

To test for starting point bias, five starting point bids were used in asking households' WTP and WTA (willingness to accept) for grazing rights. If starting point bias were a problem, the lowest starting point bid of USD0.91 per animal per year would have the lowest mean maximum willingness to pay (MWTP) or mean maximum willingness to accept (MWTA). Similarly, the highest starting point bid of USD5.48 would have the highest mean MWTP or MWTA. The results of Tables 8.1 and 8.2 seem to indicate that there is no starting point bias in household WTP or WTA for grazing rights. There is no systematic increase in the mean MWTP or MWTA as the starting point bid increases across all survey sites.

Table 8.2: Testing for starting point bias for WTA for grazing rights by Survey Site

Starting Point Bid (USD)	Nerutanga	Gaza	Chiduku	Matsika
	Mean Maximum Willingness To Accept (USD)			
0.91	13.01	30.98	6.48	5.05
1.83	6.59	11.27	7.84	5.81
2.74	10.51	15.62	3.58	10.14
3.65	4.46	25.19	5.91	6.96
4.56	7.73	28.24	7.16	8.00
5.48	4.90	20.22	16.17	7.38

must make a trade-off between money and environmental amenities.

Mean	7.90	21.47	7.21	7.24

8.1.2 Testing for vehicle bias

Vehicle bias refers to the systematic differences in valuation responses depending upon the postulated means of collecting payment from individuals (Seip and Strand, 1992; Whittington, et. al., 1990; Freeman, 1986). To test for vehicle bias, the mean MWTP for different modes of payment for grazing are compared. The modes of payment for grazing compared are (Table 8.3):

a) Payment for grazing in general,
b) Tradable grazing rights,
c) Taxing of all cattle,
d) Taxing only those with greater than four cattle, and
e) Cost of fodder production per animal per year.

Table 8.3: Testing for vehicle bias for WTP for grazing resource use

	VEHICLE				
	Grazing in general	TGR	Tax all HH*	Tax greater than 4 cattle	Fodder
Total observations	316	32	182	31	203
Mean MWTP (USD)	1.42	3.70	0.66	3.59	3.52
Standard deviation	2.88	9.16	9.16	9.40	7.11

*HH is households

The following mean MWTP pairs are not significantly different at the 10 percent level: grazing in general and taxing of only greater than four cattle; fodder production with taxing of only greater than four cattle as well as TGR; and taxing of only more than four cattle and TGR. The mean MWTP for grazing in general is significantly different from the mean MWTP for taxing all cattle and for TGR at the 5 percent level; and for fodder production at the 1 percent level. The mean MWTP for fodder production is significantly different from that of taxing all cattle at the 1 percent level. The mean MWTP for taxing all cattle is significantly different from the mean MWTP for taxing greater than four and TGR at the 5 percent and 1 percent levels respectively. Thus, there seem to be vehicle bias in household response to WTP for grazing resource use.

8.1.3 Household WTP for TGR

This section assesses household WTP for TGR when the system of TGR being used is grand-fathering. With grand-fathering, households are allocated an equal number of grazing rights for free irrespective of the number of cattle they own. The allocation of grazing rights is based on the carrying capacity of the veld. Given the estimated carrying capacity of the rangelands for the 1998/99 agricultural season the number of grazing rights a household would get for free per year is two in Gaza, three in Nerutanga and Chiduku, and four in Matsika. A household with fewer cattle than the grand-fathered number of grazing rights would have grazing rights to sell. For example, a household in Matsika with no cattle would have four grazing rights for sale whilst one with exactly four cattle would have no grazing rights for sale. A household with nine cattle would need to purchase five grazing right permits. If the household with more than four cattle is not able to secure grazing rights for all cattle, then those cattle for which grazing rights are not secured are liable to de-stocking.

The percent households owning at least the number of cattle qualifying for grand-fathering of grazing rights is 37 percent, 45.9 percent, 27.5 percent and 27.8 percent for Nerutanga, Gaza, Chiduku and Matsika respectively. Of these households, except in Nerutanga, the majority of the households are WTP for grazing rights (Figure 8.1). The main reasons forwarded for not WTP for grazing rights is that (i) it is not proper to pay for use of naturally occurring resources, and (ii) there is still enough grazing available and there is no need to pay for it (Table 8.4).

Table 8.4: Percent Large Herd HH Indicating Reasons for Not WTP for Grazing Rights by Survey Site

Reason	Nerutanga	Gaza	Chiduku	Matsika
Dont want to buy grazing rights	14.3	0.0	0.0	0.0
TGRs limit herd size	14.3	20.0	0.0	20.0
There is enough grazing	42.9	40.0	0.0	40.0
Grazing Naturally Occuring	28.6	40.0	0.0	40.0

HH - Households

An analysis of the MWTP for grazing rights by survey site shows that on average, households in Chiduku have the highest MWTP followed by households in Matsika (Table 8.1). Households in Gaza have the lowest mean MWTP. The results seem to conform to economic theory – where grazing resources are relatively scarce, the MWTP for grazing rights is high. Conversely, where grazing resources are relatively abundant, the MWTP for grazing rights is low. Grazing resources are more scarce in Chiduku communal area, hence the highest mean MWTP for grazing rights.

Figure 8.1: Percent Households not WTP nor WTA for TGR by Survey Site

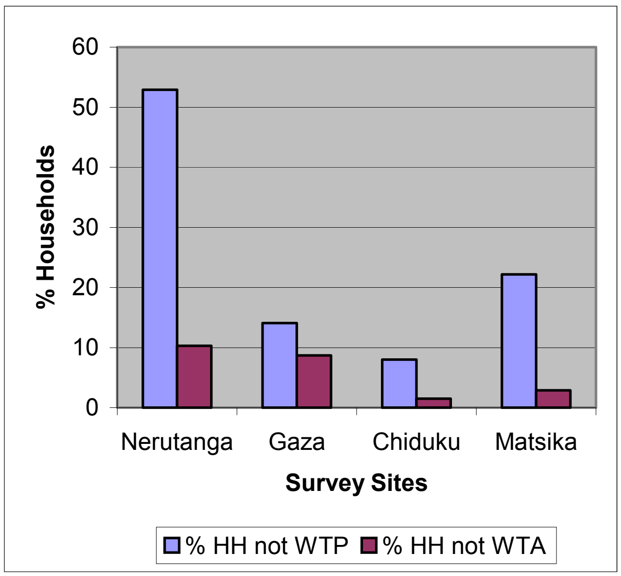


Table 8.5 shows the results of an analysis of household MWTP for TGR by several household characteristics. A high MWTP means that a set of households with a given household characteristic are not likely to de-stock with the implementation of TGR. A low MWTP means the households with a given characteristic are likely to de-stock because they may not afford to pay for the grazing right permits. On average, the poor households[23], households

[23] It should be noted that these are poor households with more cattle than the grand-fathered number of grazing rights and hence they had to respond to WTP questions. The poor households with fewer cattle than the number of grand-fathered number of grazing rights had to respond to WTA questions.

whose heads did not attend school and widow headed households are likely to de-stock with the introduction of TGR. However, the difference in MWTP is not statistically significant at the 10 percent level across: (i) wealth, education and household head sex categories in Nerutanga, (ii) sex of household head categories in Gaza; and (iii) education of household head categories in Chiduku. Thus, the policy of TGR is likely to affect negatively (in terms of cattle numbers kept only) on the poor households in Gaza, Chiduku and Matsika; households whose heads did not attend school in Gaza and Matsika; and widow headed households in Chiduku and Matsika. The least impact is likely on the rich households in Gaza, Chiduku, and Matsika, households whose heads attained secondary education in Gaza and Matsika, male headed households in Matsika and *de facto* female headed households in Chiduku.

Table 8.5: Mean Household MWTP (US$) for Grazing Rights by Selected Household Characteristics by Survey Site

Household Characteristic	Nerutanga	Gaza	Chiduku	Matsika
Wealth Status				
Rich	0.22[a]	0.37[a]	1.82[a]	0.55[a]
Medium	0.40[a]	0.03[b]	0.43[b]	0.51[ab]
Poor	0.13[a]	0.09[c]	0.13[b]	0.07[c]
Education level of household head				
Did not attend school	0.01[a]	0.01[a]	0.48[a]	0.10[a]
Primary	0.37[a]	0.10[b]	1.00[a]	0.31[ab]
Secondary	0.29[a]	0.29[c]	0.56[a]	0.83[c]
Sex of household head				
Male	0.26[a]	0.16[a]	0.48[a]	0.50[ab]
De facto female	0.43[a]	0.11[a]	1.95[b]	0.35[a]
Widow	0.19[a]	0.08[a]	0.28[ab]	0.13[b]

aa, bb, cc – Not significantly different at 10% level ab, ac, bc – Significantly different at 10% level

8.1.4 Household WTA for TGR

Of those households with relatively small cattle herds across all survey sites, at least 89 percent are WTA payment for grazing rights (Figure 8.1). The percentage households not WTA payment for grazing rights is higher in Buhera CA than in Chiduku CA. The main reason for not WTA for grazing rights is that they are already benefiting indirectly from the use of grazing resources through those with large cattle herds. These benefits include the availability of draft power, milk, and manure (Table 8.6). They are concerned that if they charge for grazing rights they may no longer receive these benefits. This can be interpreted to mean that these households expect the benefits from grazing rights to be less than the indirect benefits they are currently getting from large cattle herd owners.

Table 8.6: Percent Small Herd HH Indicating Reasons for Not WTA for Grazing Rights by Survey Site

Reason	**Nerutanga**	**Gaza**	**Chiduku**	**Matsika**
Dont want to sell grazing rights	36.4	8.3	0.0	0.0
TGRs limit herd size	9.1	25.0	0.0	50.0
There is enough grazing	27.3	8.3	0.0	50.0
Already benefit from large cattle herd owners	27.3	58.4	100.0	0.0

HH - Households

An analysis of MWTA by household characteristics is presented in Table 8.7. Given that the system of TGR is basically demand driven (see Section 8.3) an analysis of MWTA aids in identifying household categories that are likely to participate in the trade of grazing rights. *Ceteris paribus*, households with low MWTA are likely to participate and benefit in the trade of grazing rights than households with high MWTA.

Across all household categories in Nerutanga, Gaza, and Chiduku the MWTA for grazing rights is not statistically different. Thus, in these areas all households are likely to benefit from trading grazing rights. In Matsika, the household categories likely to benefit from the trade of grazing rights are poor households and households whose heads did not attend school. The household categories that are least likely to benefit from the trade in grazing rights - because as the price for grazing rights increase, the demand decreases - are rich households and households whose heads attained primary education in Matsika.

Table 8.7: Mean Household MWTA (US$) for Grazing Rights by household characteristics by survey site

Household Characteristic	Nerutanga	Gaza	Chiduku	Matsika
Wealth Status				
Rich	-	39.52[a]	5.24[a]	10.65[a]
Medium	10.97[a]	23.44[a]	5.37[a]	7.99[ab]
Poor	7.88[a]	20.10[a]	8.21[a]	5.52[b]
Education level of household head				
Did not attend school	10.92[a]	13.09[a]	4.33[a]	2.80[a]
Primary	6.41[a]	23.72[a]	7.82[a]	8.52[b]
Secondary	12.76[a]	19.24[a]	6.23[a]	7.94[c]
Sex of household head				
Male	6.15[a]	24.38[a]	6.24[a]	7.71[a]
De facto female	9.74[a]	19.96[a]	8.00[a]	6.13[a]
Widow	9.51[a]	19.22[a]	7.67[a]	8.22[a]

aa, bb, cc – Not significantly different at 10% level   ab, ac, bc – Significantly different at 10% level

8.2 Preferred Mode of payment for TGR

This section analyses the preferred mode of payment for TGR between the small and large herd owners. Households were asked of the mode of payment they would prefer for grazing rights. The options were cash or plowing. Those with large cattle herds would be expected to buy grazing rights for their cattle, whilst those with small cattle herds would be expected to sell grazing rights. The determination of the mode of payment for TGR is important when designing the intervention strategy for TGR. It would be easier to adopt a strategy that is most preferred by both small herd and large herd households as this would enable a smooth implementation of the TGR policy.

Generally, the implementation of tradable grazing rights using plowing as the mode of payment is likely to be easier in Buhera communal area than in Chiduku communal area. Except in Chiduku, at least 55 percent of the households with large cattle herds prefer plowing as the mode of payment (Table 8.8). In Chiduku, 45 percent of those with large cattle herds prefer cash as the mode of payment. Households with large cattle herds have readily available draft power and would therefore prefer plowing as the mode of payment. That large herd owners in Chiduku prefer cash as the mode of payment may be due to the fact that with the high grazing pressure in Chiduku, draft cattle may not be in good condition for plowing.

Table 8.8: Percent Households Preferring Mode of Payment for TGR by Herd Size and by Survey Site

	Nerutanga		**Gaza**		**Chiduku**		**Matsika**	
Mode of Payment	**Large herd**	**Small herd**	**Large herd**	**Small herd**	**Large herd**	**Small herd**	**Large herd**	**Small herd**
Cash	12.0	19.0	32.3	24.5	54.5	62.1	34.8	47.6
Plowing	60.0	77.6	54.8	71.4	45.5	36.4	65.2	31.7
Other	28.0	3.4	12.9	4.1	0.0	1.5	0.0	20.6
N	34	58	39	46	25	66	27	70

Of those households with small herds or no cattle, the percentage households preferring plowing as the mode payment is at least 70 percent in Nerutanga and Gaza (Table 8.8). At most 36 percent of the small herd owners in Chiduku and Matsika prefer plowing as the mode of payment for grazing rights. A substantial percentage of households in Nerutanga and Matsika indicated they would prefer other modes of payment for grazing rights other than plowing or cash. These include weeding the fields or no payment at all. Plowing is clearly the most preferred mode of payment for grazing rights by both small and large herd owners in Nerutanga. The other three survey sites would need to have households negotiate on a one-to-one basis on the preferred mode of payment as both cash and plowing can be used for the payment of grazing rights.

8.3 Estimating Demand and Supply Functions for Grazing Rights

Based on the household MWTA and MWTP for grazing rights, supply and demand functions were estimated respectively. The demand and supply functions were derived at the community level. The MWTP and MWTA is the maximum/minimum price a household is WTP/WTA per grazing right per year. To estimate the demand and supply functions, the

MWTP and MWTA are frequenced and then used to come up with a price range for grazing rights per survey site.

To estimate the demand function for those with large cattle herds, at each price level, the cumulative number of grazing rights demanded by the sample households is adjusted using the appropriate sampling fraction (see Chapter Five) to derive the cumulative number of grazing rights demanded at the community level. The cumulative number of grazing rights demanded increase as the price of grazing decreases. The price is then regressed against the cumulative number of grazing rights at each price level using ordinary least squares (OLS) estimation (Equation 8.1). A similar process is used to estimate the supply functions for grazing rights for those with small cattle herds (Equation 8.2). The only difference is that the cumulative number of grazing rights supplied increase as the price of grazing rights increase.

The estimated demand function is represented by:

$$D = \beta_0 - \beta_1 P + \mu_0 \tag{8.1}$$

The estimated supply function is represented by:

$$S = \alpha_0 + \alpha_1 P + \mu_1 \tag{8.2}$$

At the equilibrium price (P*):

$$D^* = S^* \tag{8.3}$$

Where D is the potential demand for grazing rights,

D* is the equilibrium quantity of grazing rights demanded,

S is the potential supply for grazing rights,

S* is the equilibrium quantity of grazing rights supplied,

P is the price per grazing right,

β_i and α_i are the regression coefficients for the demand and supply functions, and

μ_i are the error terms for the demand and supply functions respectively.

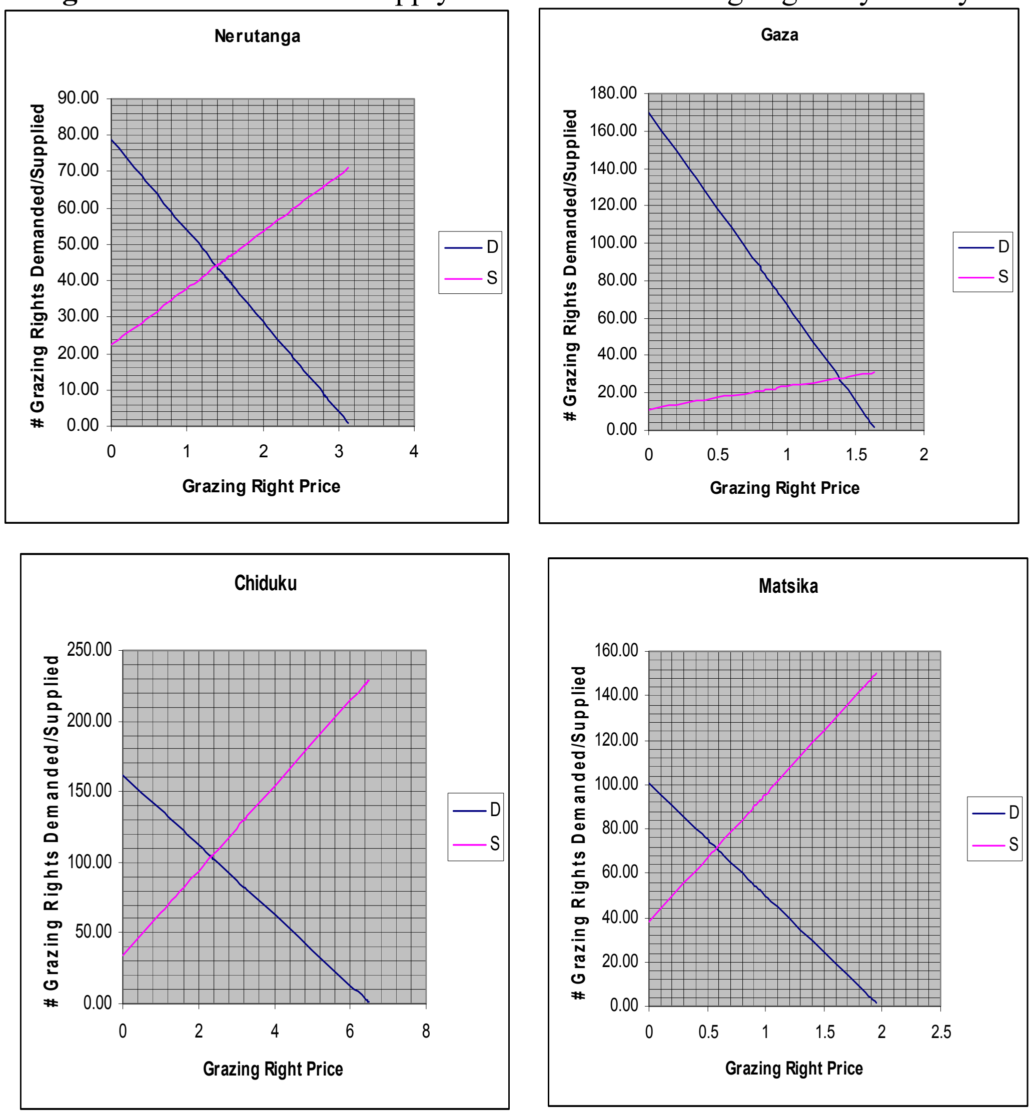
The estimated community demand and supply functions for each survey site are presented in Table 8.9. Figure 8.2 gives the graphical presentation of the demand and supply functions. The price of grazing rights explains most of the variation in the number of grazing rights demanded or supplied. This is shown by the adjusted R-squared of at least 0.48 for both demand and supply functions across survey sites. Solving each set of demand and supply functions simultaneously gives the equilibrium (or market clearing) price for grazing rights (P*). Substituting P* into either the demand or supply function gives the equilibrium quantity of grazing rights.

Table 8.9: Community Demand and Supply Functions for TGR by Survey Site

Survey site	Function	Constant	Slope	Adj. R^2	n	P* (USD)	D* = S*
Nerutanga	Demand	78.775	- 24.920[t]	0.622	35	1.39	44
		(t = 11.776)	(t = -6.747)				
	Supply	22.318	15.565	0.950	35		
		(t = 17.951)	(t = 22.692)				
Gaza	Demand	170.076	-102.669	0.480	33	1.39	28
		(t = 6.162)	(t = - 4.197)				
	Supply	11.298	11.923	0.828	33		
		(t = 7.835)	(t = 9.351)				
Chiduku	Demand	161.774	- 24.766	0.538	43	2.33	104
		(t = 9.379)	(t = - 6.639)				
	Supply	33.840	30.057	0.934	43		
		(t = 5.569)	(t = 22.877)				
Matsika	Demand	100.548	- 50.798	0.878	31	0.58	71
		(t = 17.707)	(t = 11.419)				
	Supply	38.064	57.492	0.734	31		
		(t = 3.688)	(t = 7.111)				

[t] To convert to Z$ equivalent demand and supply functions, divide slope and price (P*) by 38.338 (the exchange rate to the USD, 1999). The constants and t-values remain the same.

Figure 8.2: Demand and Supply Functions for Grazing Rights by Survey Site



8.3.1 Elasticity of demand and supply

After the estimation of the demand and supply functions for grazing rights, the next step is to analyze the degree of the likely response to price changes in grazing rights. A measure of response to price changes is the elasticity. The price elasticity of demand is defined as the proportionate change in the quantity of grazing rights demanded divided by the proportionate change in price, i.e.:

$$\varepsilon^{d}_{p} = -\frac{dD}{dP}\left(\frac{P}{D}\right)$$

(8.4)

Similarly, the price elasticity of supply is the proportionate change in the quantity of grazing rights supplied divided by the proportionate change in price, i.e.:

$$\varepsilon^{s}_{p} = \frac{dS}{dP}\left(\frac{P}{S}\right)$$

(8.5)

Since the gradient or slope along each of the demand or supply functions is constant, then the price elasticity demand or supply will vary at different points along the curve. When $\varepsilon^{d}_{p} > 1$, then the demand for grazing rights is elastic, i.e. a proportionate change in price will result in a more than proportionate change in the quantity of grazing rights demanded. When $\varepsilon^{d}_{p} < 1$, then demand is inelastic meaning that a proportionate change in price would result in a less than proportionate change in the quantity of grazing rights demanded. Similarly when $\varepsilon^{s}_{p} > 1$, then the supply of grazing rights is elastic and when $\varepsilon^{s}_{p} < 1$ the supply is inelastic.

The supply functions across all survey sites are inelastic over the relevant price range of the functions. This means a 10 percent increase in the price of grazing rights results in a less than 10 percent increase in the quantity of grazing rights supplied. At equilibrium, the supply response to grazing right price changes is highest for Chiduku and lowest for Matsika. At equilibrium price, ε^{s}_{p} is 0.47, 0.49, 0.59 and 0.67 for Matsika, Nerutanga, Gaza and Chiduku respectively. This means, for example, a ten percent increase in the price of grazing rights in Chiduku will result in a 6.7 percent increase in the supply of grazing rights.

An analysis of the demand functions show that the demand functions are inelastic below a price of USD3.27, USD0.99, USD0.83 and USD1.46 in Chiduku, Matsika, Gaza and Nerutanga respectively. At the equilibrium, ε^{d}_{p} is 0.41, 0.55, 0.78 and 5.21 for Matsika, Chiduku, Nerutanga and Gaza respectively. This means, for example, a 10 percent increase in the price of grazing rights in Chiduku will result in a 5.5 percent decrease in the quantity of grazing rights demanded. The price response for Gaza is elastic. A 10 percent increase in the price of grazing rights would result in a 2.1 percent decrease in the demand for grazing rights. Thus, at equilibrium, the demand response to price changes is higher in Buhera communal when compared to Chiduku communal area.

8.4 Potential impact of implementing TGR on agricultural productivity

This section analyses the potential impact of TGR on a number of performance indicators:

i. Grazing pressure,
ii. Cattle herd performance,
iii. Plowing rates,
iv. Maize yields, and
v. Milk yields.

Once the production functions for these impact indicators produce satisfactory results, they are then used or incorporated into the linear programming (LP) model developed in Chapter Nine. Whilst this section analyses the impact of TGR when each performance variable is evaluated individually, Chapter Nine will assess the impact of TGR when the performance variables are considered together with the farm production constraints that farmers face.

The impact of TGR on the performance indicators is measured using production functions that relate the level of performance to grazing pressure. Grazing pressure – denoted as GP - is captured as the actual stoker days per hectare per year divided by the recommended stoker days per hectare per year, i.e. ASD/RSD (see Chapter 6) given the 1999 rainfall levels. GP depicts the level of over-stocking or under-stocking in any given season. GP is used to capture the externality effects of overgrazing on the selected performance indicators.

The results on each performance indicator are presented for the following scenarios:

i. without TGR, and
ii. with TGR at the equilibrium level of grazing,

8.4.1 Potential impact of implementing TGR on grazing pressure

Using the demand functions derived for grazing rights in Section 8.3, the potential number of cattle that a community would keep at given TGR prices can be estimated. The results show that Gaza is the most responsive to an introduction of TGR followed by Nerutanga (Table 8.10). At equilibrium price, the community herd would decrease by about 41 percent in Gaza and 11 percent in Nerutanga. The percentage herd decrease is similar for Chiduku and Matsika at the equilibrium price.

Table 8.10: Herd Characteristics at Equilibrium Price by Survey Site

Characteristic	Nerutanga	Gaza	Chiduku	Matsika
% Herd decrease with TGR	10.57	40.77	7.85	6.92
SD/ha/year at equilibrium	54.3	37.7	78.7	64.5
SD/ha/year at P* = 0	60.8	63.6	85.4	69.3
Recommended SD ha^{-1} yr^{-1}	97.0	67.0	83.0	95.0
Worst case recommended SD $ha^{-1}yr^{-1}$	51.0	7.0	41.0	35.0

The question that can be posed is would the introduction of tradable grazing right policy result in an enough decrease in herd size such that rangelands are not overstocked? Comparing the stoker days (SD) per hectare per year at equilibrium and the recommended SD shows that TGR result in reduced grazing pressure (Table 8.10). This is particularly so in Chiduku which is initially slightly over grazed without TGR (i.e. 85.4 SD per ha per annum) but is grazing below the recommended rate with grazing rights (i.e. 78.7 SD per ha per annum).

Whilst the results show that TGR may result in environmental improvement due to reduced grazing pressure under normal rainfall conditions, under extremely harsh weather conditions, on their own, TGR may not be effective in controlling overstocking. This is particularly so given that communal area farmers do not easily increase their cattle off-take as a means of reducing risk in response to bad weather. For example, in Matsika, under a severe drought, the recommended stocking would be 35 SD per ha per annum. TGR would encourage farmers to reduce their herd size to almost double this recommended stocking level (i.e. 64 SD per ha per annum).

8.4.2 Potential impact of implementing TGR on cattle herd performance

The following cattle herd performance production functions[24] were estimated:

$$CfMRate = 0.05 + 0.0525*ASD/RSD \quad (8.9)$$

$$AdMRate = 0.03 + 0.0205*ASD/RSD \quad (8.10)$$

$$CalvRate = 0.75 - 0.234*ASD/RSD \quad (8.11)$$

Where CfMRate is the calf mortality rate,

AdMRate is the adult cattle mortality rate, and

CalvRate is the calving rate.

From Equations 8.9 and 8.10, the calf and adult cattle mortality rates increase as grazing pressure (GP) increases. Equation 8.11 says that calving rates decrease as GP increases. Table 8.11 shows that with TGR there are improvements in the calving rate, calf and adult cattle mortality rates. Matsika has the lowest improvement in the herd performance with TGR with 0.26, 0.11 and 1.19 percentage point increases in the calf mortality rate, the adult cattle mortality rate and the calving rate respectively. Gaza has the highest improvement in the herd performance with 2.03, 0.79 and 9.05 percentage point increases in the calf mortality

[24] Due to lack of time series data over a much longer period, the cattle herd performance production functions were estimated from household survey datafor a ten year period 1989 to 1999. Due to the short time horizon for which data was available, these functions are not statistically significant. However, they are deemed reasonable functions because they represent well the data for the 1990s for which survey data was collected.

rate, the adult cattle mortality rate and the calving rate respectively. The results seem to indicate that the impact of TGR on cattle herd performance is likely to be positive and greatest in the dry and overstocked regions and the least in the relatively wet regions.

Table 8.11: Herd performance with and without TGR by Survey Site

	Nerutanga	Gaza	Chiduku	Matsika
Performance without TGR				
- Calf mortality (%)	9.28	10.51	10.40	8.83
- Adult mortality (%)	4.67	5.15	5.11	4.50
- Calving rate (%)	55.91	50.44	50.92	57.92
Performance with TGR at equilibrium				
- Calf mortality (%)	8.93	8.48	9.98	8.57
- Adult mortality (%)	4.54	4.36	4.94	4.39
- Calving rate (%)	57.46	59.49	52.82	59.11

8.4.3 Potential impact of implementing TGR on plowing rates

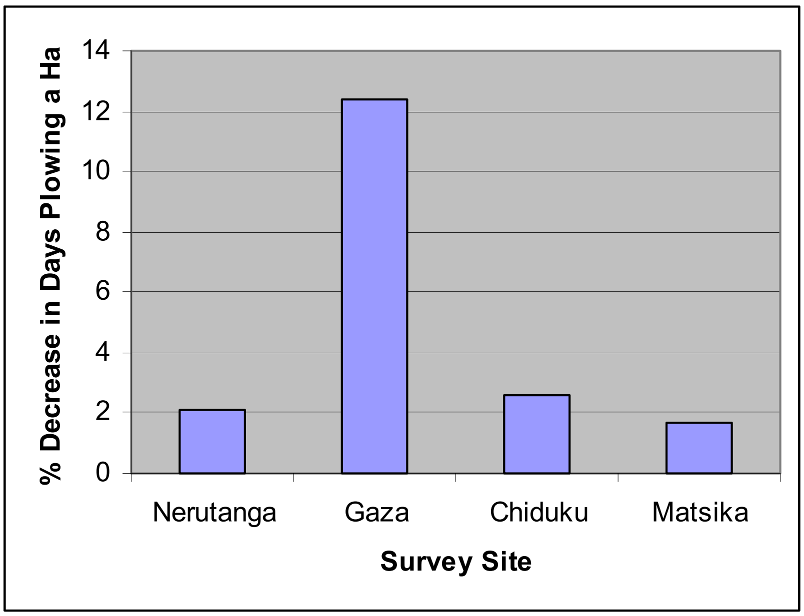
Due to lack of time series data as well as cross-section data, the plowing rate function was estimated crudely based on secondary information. A pair of oxen in good condition takes about 3.3 days to plow a hectare of land whilst a pair of oxen in poor condition takes more than 3.3 days (Guveya, 1995). As GP increases, oxen are weaker and hence take more time to plow a hectare of land. Conversely, as the GP decreases, oxen are in good condition and it takes less time to plow a hectare of land (Equation 8.12):

$$PR = 3 + 1.429 \frac{ASD}{RSD} \tag{8.12}$$

where PR is the plowing rate (days per hectare per pair of oxen).

Figure 8.3 shows the percentage decrease in the number of days to plow a hectare of land with TGR compared to without TGR. The highest improvement in the plowing rate is likely to be in Gaza and the least improvement is likely to be in Matsika. As the plowing rate improves, it is expected that, *ceteris paribus*, maize yields are likely to increase. This is because improved plowing rates result in timely planting with the onset of the rains, hence the increased maize yields.

Figure 8.3: Percent decrease in the number of days taken to plow a hectare with TGR versus the status quo



8.4.4 Potential impact of implementing TGR on maize yields

Maize yield functions were estimated using time series data from 1954 to 1998 for the respective survey. The secondary data had estimates for the following variables at the community level: number of cattle, area under maize, maize yields, and fertilizer use. Maize yield (MzYild) in kilograms per hectare, is a function of rainfall (Rain) (mm), the amount of nutrients applied (Nutrient) and GP (Equation 8.13). The functional form estimated is:

$$MzYild = \alpha_0 Rain + \alpha_1 Nutrient - \alpha_2 ASD/RSD + \varepsilon \qquad (8.13)$$

Where ε is the error term.

The variable Nutrient measures the sum of fertilizer used (kilograms of ammonium nitrate and Compound D) per hectare plus the amount of cattle manure nitrogen[25] applied (kg) per hectare. It is assumed that all the cattle manure produced is applied to the maize crop. The fertilizer application rates per hectare, based on survey data, are presented in Table 8.12. Maize yields are expected to increase with an increase in rainfall and the amount of nutrients applied and decreases as GP increases.

Table 8.12: Estimated fertilizer application rates[+] (kg/ha) by Survey Site

	Nerutanga	**Gaza**	**Chiduku**	**Matsika**
- Large herd (LH) households	63.17	85.47	106.33	96.56
- Small herd (SH) households	45.33	89.68	83.78	95.46

[+] Sum of ammonium nitrate and compound D

The regression model for maize yield passes through the origin. This is because at zero rainfall or nutrients, yields will be zero. With respect to nutrients, the soils in the study areas are sandy and very low in soil nutrients. The data was tested for autocorrelation or serial correlation and multicollinearity using the Durban-Watson (DW) statistic and the Condition Index (CI) respectively (Gujarati, 1988; Greene, 1990). Autocorrelation is a frequent problem associated with time series data and occurs when there is a relationship between the successive values of the same variable over time. Multicollinearity occurs when there is a perfect or near perfect linear relationship among some or all explanatory variables of a regression model. Autocorrelation and multicollinearity result in statistically unbiased parameter estimates. However, the variances of the parameter estimates are larger resulting in statistically insignificant parameter estimates. As a rule of thumb, if DW is around 2, then it can be assumed there is no first-order autocorrelation. If the CI is less than 10, it can be

[25] It is assumed that 1 LU produces 500 kg of dry matter (DM) manure per year (Caron et. al., 1998; GFA, 1987). The nitrogen content of the manure is assumed to be 1.04 percent of DM (Caron et. al., 1998; Steinfeld, 1988). The analysis presented in this thesis assumes that the N-content of the cattle manure does not increase with an improvement in veld/pasture condition.

assumed that there is no multicollinearity; if the CI ranges from 10 to 30, there is moderate to strong multicollinearity; and if the CI is greater than 30, then there is severe multicollinearity. The data did not show the presence of autocorrelation nor multicollinearity.

The estimated maize yield functions are presented in Table 8.13. As expected, across all survey sites, maize yields increase with an increase in rainfall and the amount of nutrients applied per hectare and maize yields decrease with an increase in GP. However the GP coefficients for Nerutanga and Matsika are not significant at the 10% level. Table 8.14 shows the potential impact of TGR, the Nutrient and GP variables, on maize yields for the 1998/1999 cropping season. The yields are estimated for large herd (LH) households and small herd (SH) households.

Table 8.13: Maize yield functions parameters by Survey Site

	Nerutanga			**Gaza**			**Chiduku**			**Matsika**		
	Coeff.	**t-value**	**Sig.**	**Coeff.**	**t-value**	**Sig.**	**Coeff.**	**t-value**	**Sig.**	**Coeff.**	**t-value**	**Sig.**
- Rainfall	0.392	3.309	0.002	0.184	2.921	0.006	0.333	2.364	0.023	0.447	4.151	0.000
- Nutrient	40.442	3.152	0.003	20.861	6.186	0.000	29.614	4.030	0.000	42.666	3.675	0.001
- $\frac{ASD}{RSD}$	-20.855	-0.125	0.901	-33.289	-2.143	0.038	-182.652	-1.625	0.112	-131.236	-0.738	0.465
- Adj. R^2	0.877			0.903			0.89			0.895		
- DW statistic	2.096			1.818			1.612			1.961		
- Condition Index	7.508			5.238			9.088			7.275		
- N	44			44			44			44		

Table 8.14: Potential maize yields (kg/ha) with and without TGR by herd size category by Survey Site

	Nerutanga	**Gaza**	**Chiduku**	**Matsika**
Performance without TGR				
- Large herd households	1244	647	1248	1692
- Small herd households	1017	552	967	1634
Performance with TGR at equilibrium				
- Large herd households	1240	673	1260	1693
- Small herd households	1018	602	985	1641

Due to their higher rate of fertilizer and cattle manure application per hectare, LH households have higher maize yields than SH households. Comparing the maize yields with TGR at the equilibrium price level for grazing rights and the status quo shows the following:

- maize yields for LH households in Chiduku and Gaza increase by 1 percent and 4 percent respectively,
- there are no changes in maize yields for LH households in Matsika,
- maize yields in Nerutanga decrease by about 0.3 percent for LH households,
- maize yields for SH households increase by 0.4, 1.9 and 9.1 percent in Matsika, Chiduku and Gaza respectively, and
- there are no changes in maize yields for SH households in Nerutanga.

Thus, except for LH households in Nerutanga where maize yields decrease with TGR, maize yields at least increase with TGR. This is due to an improvement in cattle condition which positively affects the plowing rates, hence planting dates and hence maize yields. For LH households, with TGR, the number of cattle kept decreases, hence there is less manure to apply to the maize crop. That maize yields for LH households in Gaza and Chiduku increase with TGR shows that though less output is realized due a decrease in cattle numbers, maize productivity may be enhanced due to the improved plowing rates. The results suggest that the impact of TGR on maize yields is likely to be very small; with the relatively dry agro-ecological regions having higher maize yield impacts.

8.4.5 Potential impact of implementing TGR on milk yields

The milk yields were estimated from milk yield functions that were intuitively derived. The intercepts for the production function for each survey site are agro-ecological region dependent (Guveya, 1995). The production functions shown in Table 8.15 were calibrated to reflect the milk yields for the 1996/97 and 1998/99 seasons. The production functions estimated the milk yields without TGR very well. It is assumed that milk yields decrease with an increase in GP. Conversely, milk yields increase with a decrease in grazing pressure. Based on the derived milk yield functions and the demand functions for TGR, milk yields with and without TGR are presented in Table 8.16.

Table 8.15: Milk yield (liters per lactation) functions by Survey Site

	Nerutanga	**Gaza**	**Chiduku**	**Matsika**
Intercept	298	185	285	325
Slope ($\frac{ASD}{RSD}$)	-205.9	-26.33	-106.91	-119.22

Table 8.16: Potential milk yield (liters per lactation) with and without TGR by Survey Site

	Nerutanga	**Gaza**	**Chiduku**	**Matsika**
Milk yield without TGR	130	157	175	238
Milk yield with TGR at equilibrium	143	167	183	244

The highest improvement in milk yields is likely to be in Nerutanga (10 percent). The lowest yield improvement is likely to be in Matsika (2.5 percent). Gaza and Chiduku are likely to have milk yield improvements of 6.4 and 4.6 percent respectively. Thus, the highest milk yield improvements with TGR are likely to be in relatively wet regions with relatively low grazing pressure whilst the lowest improvements are likely to be in the wet regions with relatively high grazing pressure.

8.5 Summary

This Chapter analyzed households' attitudes towards TGR through household willingness to pay (WTP) and willingness to accept (WTA) for TGR and the preferred mode of payment for TGR. Based on the maximum willingness to pay (MWTP) and minimum willingness to accept (MWTA) for grazing rights, the chapter estimates potential demand and supply functions for grazing rights. The estimated demand and supply functions are used to estimate the potential equilibrium prices for grazing rights. Based on the derived demand functions for grazing rights, the potential impact of TGR on grazing pressure, cattle herd performance parameters, plowing rates, maize yields and milk yields are estimated. An analysis of household MWTP for TGR shows that the poor households in Gaza, Chiduku and Matsika; households whose heads did not attend school in Gaza and Matsika; and widow headed households in Chiduku and

Matsika are not likely to afford to pay for grazing rights hence they are likely to de-stock first with the introduction of TGR. An analysis of MWTA shows that all household categories in Nerutanga, Gaza, and Chiduku are likely to benefit from trading grazing rights. In Matsika, the household categories likely to benefit from the trade of grazing rights are poor households and households whose heads did not attend school. This is because these households have a low MWTA for grazing rights. Other household categories with high MWTA for grazing rights are unlikely to benefit from the trade in grazing rights.

An analysis of the preferred mode of payment for grazing rights shows that generally, the implementation of tradable grazing rights using plowing as the mode of payment is likely to be easier in Buhera communal area than in Chiduku communal area. Plowing is clearly the most preferred mode of payment for grazing rights by both small and large herd owners in Nerutanga. In the other three survey sites, both cash and plowing can be used for the payment of grazing rights.

Using the demand functions derived for grazing rights, the results indicate that under normal rainfall conditions, TGR result in range improvement due to reduced grazing pressure, *ceteris paribus*. With severe droughts, however, TGR may not be effective in controlling overstocking. With TGR there are also likely to be improvements in cattle herd performance and milk yields. The results indicate that the impact of TGR on cattle herd performance is likely to be positive and greatest in the dry and overstocked regions and the least in the relatively wet regions. With respect to milk yields, the highest milk yield improvements with TGR are likely to be in relatively wet regions with relatively low grazing pressure whilst the lowest improvements are likely to be in the wet regions with relatively high grazing pressure.

The results show that the impact of TGR on maize yields is likely to be very small; with the relatively dry agro-ecological regions having higher maize yield impacts. The improvements in maize yields in the dry agro-ecological regions is mainly due to an improvement in cattle condition which positively affects the plowing rates, hence planting dates and hence maize yields.

CHAPTER IX: ESTIMATING THE COST-EFFECTIVENESS, DISTRIBUTIONAL, ENVIRONMENTAL AND FOOD SECURITY IMPACTS OF TRADABLE GRAZING RIGHTS: A RECURSIVE BIO-ECONOMIC LINEAR PROGRAMMING APPROACH

9.0 INTRODUCTION

Given that TGR may have considerable support from some sections of the communal area community, this chapter aims to develop a bio-economic linear programming (LP) model to assess *ex ante* the cost-effectiveness, equity and food security impacts of adopting TGR versus the status quo. The bio-economic LP model developed here is an operationalization and empirical estimation of the theoretical concepts reviewed in Chapter 4. The hypotheses addressed in this chapter are:

1. Grazing resource allocation using TGR is more efficient and equitable than the status quo,
2. Grazing resource management under TGR has positive environmental impacts, and
3. Community level food self-sufficiency is higher with TGR than the status quo.

Section 9.1 presents a specification of the bio-economic linear programming model, i.e. the objective function subject to cattle producton, milk production, crop production and budget constraints. Section 9.2 commences by presenting a summary comparison of the base (Year 0) results and survey results to assess the extent to which the model represents the communal areas under study. The Section then proceeds to assess the costs effectiveness, distributional impacts, environmental impacts and food security impacts of tradable grazing rights *viz a viz* the status quo. Section 9.3 presents a summary and conclusion of the chapter.

9.1 Model Specification

A recursive bio-economic linear programming model is developed. The model, developed at a community level, includes two types of cattle owners – those with small cattle herds, designated as SH households and those with large cattle herds, designated as LH households. SH households are those households who have fewer cattle than the grandfathered number of grazing rights to ensure grazing within the carrying capacity of any given area. The SH households include those households who do not own cattle. LH households are those households who have more cattle than the grandfathered number of grazing rights. These groups form two farm sub-models within the community model.

The model maximizes the aggregate gross margin of the whole community over a five-year period with and without TGR. Following Torell et. al., (1991), in the recursive model, the optimal solution for the first year of the planning horizon becomes the initial resource constraint for a new model that is solved for the following year. The process is repeated each year until year five. The variable carried over in this manner is the number of cattle grazed. The key assumptions of the modeling process are described in the following section.

The scale of the model is the full village territory including the pastures. However, the areas under other villages, where the villagers migrate to get grazing are not included in the village territory and hence in the model. The communal farming systems being modeled are less specialized when compared to the commercial sector. A large range of activities are interlinked – crops, livestock, woodlands and off-farm activities. In order to track the results of modeling a complex relationship of the livestock-rangeland-crop linkages a simplified model is developed.

For purposes of this model, there are two basic activities undertaken for cash and subsistence by most households in the study sites. These are agricultural crop production and livestock herding. The crops and livestock are a source of food for domestic use and sale. There are several other important activities, e.g. off-farm work and making crafts, and firewood collection which are not individually modeled. These activities are a source of income or they affect the allocation of labour resources for cropping and tending to livestock. The income from these activities is however reflected in the budget constraint. To deal with the issue of labour allocation to other activities, the model assumes the percentage available labor that is allocated to crop and livestock production, thus leaving the rest of the labour to be allocated to these other activities.

There are a number of livestock types kept by the local communities of which the main ones are cattle and goats. Other livestock include donkeys, chicken and pigs. For purposes of this study, cattle are assumed to be the only grazing livestock held by communal area farmers. This assumption is reasonable given that a) about 80 percent of the communal livestock are cattle (Ndlovu, 1990); b) cattle are grazers whilst small ruminants are mainly browsers and thus they impact on different components of grazing resources.

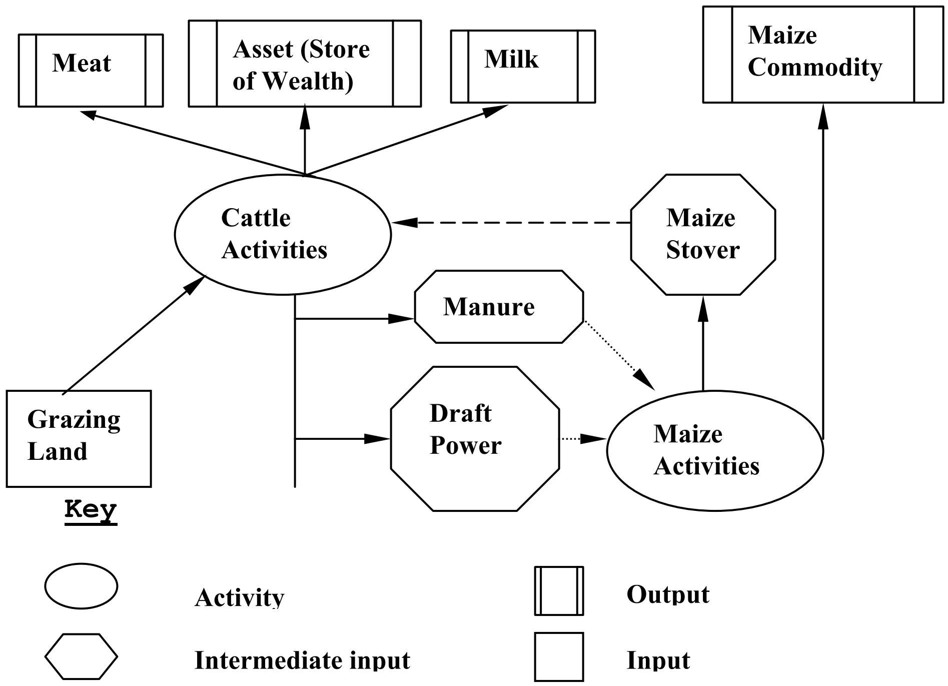
The major crop produced by the households across all the survey sites is maize. Other crops include sorghum, cow peas, and millets. It is assumed that the only crop produced by communal area farmers is maize, even in the low agricultural potential regions i.e. NR IV and V. This assumption is also reasonable given that in the study areas at least 95 percent of all the households produce maize and at least 60 percent of all cropped area is under maize. The biophysical component of the model developed here links grazing quality, - as measured by stocking rates or grazing pressure - livestock productivity and crop productivity given constraints in land under grazing and arable production, range productivity, and cattle feed intake. The economic component put prices (costs and returns) to the cattle and maize outputs, subject to budget and labor constraints.

The available household labor in the study sites is constrained by the active population residing in each study site. The number of residents per site is given exogenously. The LH households can hire labor from the SH households. It is assumed that there is no hiring of labor outside the community boundaries. The transactions of labor within the community are driven by the shadow price of labor during the year, which is exogenous to the model.

Figure 9.1 presents a simplified diagram of the cattle-crop production linkages that exist in the communal areas. The model assumes that cattle activities produce three outputs:

i. the cattle commodities – milk and animals for sale,
ii. manure, and
iii. draft power.

Figure 9.1: Cattle-Crop Production Linkages



Manure and draft power are used as intermediate inputs in the maize production activities (indicated by the dashed arrows from draft power and manure to maize activities in the figure). The maize activities produce two outputs or commodities:

i. the maize commodity, and
ii. crop residues or stover.

The stover is used as an intermediate input in cattle production activities (indicated by the dashed arrow from maize stover to cattle activities in the figure). The model assumes that there is no external injection of cattle numbers from outside the community. When a household buys or sells cattle, these transactions are done within the community.

9.1.1 Objective function

The village community allocates labor, land, and cash to crop and livestock production so as to maximize the community's crop and livestock production gross margin (Equation 9.1). The optimization problem is considered under two regimes, namely a regime where utilization of grazing resources is restricted through the use of tradable grazing rights and under an open access situation, i.e. the status quo.

$$\begin{aligned} \text{Max GM} = & -C_M{*}armzLg - C_M{*}armzSm - C_C{*}CatLULg - C_C{*}CatLUSm \\ & - C_D{*}OxInSm - w{*}LabInLg + w{*}LabOutSm + C_D{*}OxOutLg \\ & - GRPrice{*}TGRDem + GRPrice{*}TGRSuply + P_{mz}{*}MzSaleLg \\ & + P_{mz}{*}MzSaleSm + P_{cat}{*}CatSaleLg + P_{cat}{*}CatSaleSm \\ & + P_{mk}{*}MilkSaleLg + P_{mk}{*}MilkSaleSm \end{aligned} \qquad (9.1)$$

where GM is the community gross margin (USD)

C_M is the cost of producing maize per ha (USD)

armzLg is the area under maize (ha) for LH households

armzSm is the area under maize (ha) for SH households

C_C is the annual cost of keeping cattle per livestock unit (USD)

CatLULg is the number of LU kept by LH households

CatLUSm is the number of LU kept by SH households

OxInSm is draft power days hired-in by SH households

OxOutLg is draft power days hired-out by LH households

C_D is the price of draft power per ha (USD)

LabInLg is the amount of labour hired-in by LH households

LabOutSm is the amount of labour hired-out by SH households

w is the local community wage rate per day (USD)

MzSaleLg is the amount of maize sold by LH households (kg)

MzSaleSm is the amount of maize sold by SH households (kg)

P_{mz} is the selling price for maize per kilogram (USD)

CatSaleLg is the number of cattle sold by LH households

CatSaleSm is the number of cattle sold by SH households

P_{cat} is the price per unit cattle sold (USD)

MilkSaleLg is the amount of milk produced (liters) by LH households

MilkSaleSm is the amount of milk produced (liters) by SH households

P_{mk}	is the price per liter of milk (USD)
GRPrice	is the price per unit of grazing right (USD)
TGRDem	is the amount of grazing rights demanded by LH households
TGRSuply	is the amount of grazing rights supplied by SH households

The community gross margin (GM) is composed of the costs of producing maize by LH and SH households (C_M*armzLg and C_M*armzSm); the costs of keeping cattle by LH and SH households (C_C*CatLULg and C_C*CatLUSm); the costs of hiring-in labor by LH households (w*LabInLg); the costs of hiring-in draft power by SH households (C_D*OxInSm); the cost of purchasing grazing rights by LH households (GRPrice*TGRDem); revenue from the sale of maize by LH and SH households (P_{mz}*MzSaleLg and P_{mz}*MzSaleSm); the revenue from hiring out draft power by LH households (C_D*OxOutLg); the revenue from hiring out labour by SH households (w*LabOutSm); revenue from sales of grazing rights by SH households (GRPrice*TGRSuply); revenue from sale of cattle (P_{cat}*CatSaleLg and P_{cat}*CatSaleSm), and revenue from the sale of milk by cattle owners (P_{mk}*MilkSaleLg and P_{mk}*MilkSaleSm). Equations 9.1.1 and 9.1.2 present the dis-aggregated gross margins for LH and SH households respectively.

$$GMLg = - C_M*armzLg - C_C*CatLULg - w*LabInLg - GRPrice*TGRDem + C_D*OxOutLg + P_{mz}*MzSaleLg + P_{cat}*CatSaleLg + P_{mk}*MilkSaleLg \quad (9.1.1)$$

$$GMSm = - C_M*armzSm - C_C*CatLUSm - C_D*OxInSm + w*LabOutSm + GRPrice*TGRSuply + P_{mz}*MzSaleSm + P_{cat}*CatSaleSm + P_{mk}*MilkSaleSm \quad (9.1.2)$$

where GMLg is the gross margin for LH households, and

GMSm is the gross margin for SH households.

Based on (9.1.1) and (9.1.2) the gross margin per household by household category is obtained by dividing the gross margin for the household category by the number of households in that category (Equations 9.1.1.1 and 9.1.2.1):

$$GMpHHDLg = GMLg/NoHHDLg \qquad (9.1.1.1)$$

$$GMpHHDSm = GMSm/NoHHDSm \qquad (9.1.2.1)$$

where GMpHHDLg is the gross margin per household for LH households,
GMpHHDSm is the gross margin per household for SH households,
NoHHDLg is the number of households for LH households, and
NoHHDSm is the number of households for SH households.

The objective function (Equation 9.1) is subject to the following constraints:

- veld carrying capacity and the level of stocking,
- cattle production potential,
- draft power availability,
- supply and utilization of the maize crop residues,
- milk production potential,
- labour availability,
- the availability of cash to finance crop and livestock production inputs and services,
- the tradable grazing right constraint, and
- land availability.

9.1.2 Herd composition and off-take rates

Based on the survey data, the opening cattle herd sizes per household category are given by Equations 9.2.1 and 9.2.2. Equation 9.2.3 defines the aggregate opening cattle herd size for a given community.

$$CatLg = \alpha_1 \qquad (9.2.1)$$

$$CatSm = \alpha_2 \qquad (9.2.2)$$

$$CatAll = CatLg + CatSm \quad (9.2.3)$$

where CatLg is the number of cattle owned by LH households,
CatSm is the number of cattle owned by SH households,
α_1 and α_2 are the numerical values of the number of cattle owned, and
CatAll is the aggregate number of cattle owned by the community.

Equations 9.2.1.1, 9.2.2.1, and 9.2.3.1 converts the number of cattle owned into livestock units (LU).

$$CatLULg = CatLg*0.8 \quad (9.2.1.1)$$

$$CatLUSm = CatSm*0.8 \quad (9.2.2.1)$$

$$CatLUAll = CatAll*0.8 \quad (9.2.3.1)$$

Of the total cattle opening herd, β percent are cows and γ percent are oxen (Equations 9.2.4.1 and 9.2.4.2):

$$PercentCow = \beta \quad (9.2.4.1)$$

$$PercentOx = \gamma \quad (9.2.4.2)$$

The off-take rate is given by Equation 9.2.5:

$$CullratePc = \varphi \quad (9.2.5)$$

where CullratePc is the off-take or culling rate (percent).

9.1.3 Herd performance parameters

The herd performance parameters are defined as a function of the actual stoker days (ASD) divided by the recommended stoker days (RSD). The ASD/RSD makes the performance parameter depend on the grazing pressure (GP) level. The herd performance parameters are presented in Equations 9.2.6.1 to 9.2.6.3 following from Section 8.4.2. Equations 9.2.6.1 and 9.2.6.2 indicate that the calf and adult cattle mortality rates increase with an increase in GP whilst Equation 9.2.6.3 indicates that the calving rate decreases with an increase in GP.

$$\text{CalfMortPc} = 0.05 + 0.0525 * \frac{ASD}{RSD} \qquad (9.2.6.1)$$

$$\text{AdultMortPc} = 0.03 + 0.0205 * \frac{ASD}{RSD} \qquad (9.2.6.2)$$

$$\text{CalveRatePc} = 0.75 - 0.234 * \frac{ASD}{RSD} \qquad (9.2.6.3)$$

where CalfMortPc is calf mortality rate (percent),
AdultMortPc is the adult cattle mortality rate (percent), and
CalveRatePc is the calving rate (percent).

9.1.4 Herd dynamics

Given the herd performance parameters, the herd dynamics for the two household categories in the short-run are represented in Equations 9.2.7 and 9.2.8. The number of calves born in a given year is the product of the opening herd, the percentage cows in the herd and the calving rate (Equations 9.2.7.1 and 9.2.7.2). Of those calves born, some of them die. This is presented in Equations 9.2.7.3 and 9.2.7.4 as the product of the number of calves born and the calf mortality rate. Similarly, the adult cattle mortality is obtained as the product of the number of cattle owned and the adult cattle mortality rate (Equations 9.2.7.5 and 9.2.7.6). The number of cattle sold is estimated by multiplying the number of cattle owned at the beginning of the year by the culling or off-take rate (Equations 9.2.7.7 and 9.2.7.8). The closing herd per household category is obtained as the opening herd plus the number of calves born, minus the calf and adult mortalities minus cattle sales (Equations 9.2.81 and 9.2.8.2).

The closing herd for the community is the sum of the closing herds for LH and SH households (Equation 9.2.8.3). To convert the closing herd sizes to LU, Equations 9.2.8.1 to 9.2.8.3 are multiplied by 0.8 to obtain Equations 9.2.9.1 to 9.2.9.3 for the LH, SH and community closing LUs respectively.

$$CalvesLg = CatLg*PercentCow*CalveRatePc \quad (9.2.7.1)$$

$$CalvesSm = CatSm*PercentCow*CalveRatePc \quad (9.2.7.2)$$

$$NCalfMortLg = CalvesLg*CalfMortPc \quad (9.2.7.3)$$

$$NCalfMortSm = CalvesSm*CalfMortPc \quad (9.2.7.4)$$

$$NAdltMortLg = CatLg*AdultMortPc \quad (9.2.7.5)$$

$$NAdltMortSm = CatSm*AdultMortPc \quad (9.2.7.6)$$

$$CatSaleLg = CatLg*CullratePc \quad (9.2.7.7)$$

$$CatSaleSm = CatSm*CullratePc \quad (9.2.7.8)$$

$$CloseCatLg = CatLg + CalvesLg - NcalfMortLg - NadltMortLg - CatSaleLg \quad (9.2.8.1)$$

$$CloseCatSm = CatSm + CalvesSm - NcalfMortSm - NadltMortSm - CatSaleSm \quad (9.2.8.2)$$

$$ClseHerdAll = CloseCatLg + CloseCatSm \quad (9.2.8.3)$$

$$ClseCatLULg = CloseCatLg*0.8 \quad (9.2.9.1)$$

$$ClseCatLUSm = CloseCatSm*0.8 \quad (9.2.9.2)$$

$$ClseHdLUAll = ClseHerdAll*0.8 \quad (9.2.9.3)$$

9.1.5 Carrying capacity and stocking rate constraint

The carrying capacity is determined by the amount of feed that can be generated from the veld (Equation 9.3.1) as well as from the cultivated lands (Equation 9.3.3). Details are given in Chapter 6, Equations 6.1 to 6.8. Feed available from the rangelands (kg DM) is given by the following rangeland production function:

$$RF = 100 + 2.714*Rain \quad (9.3.1)$$

Where RF is the rangeland feed production per ha (kg DM),

Rain is annual precipitation (mm) adjusted for run-off.

Subtracting the minimum protective cover required per hectare of 200 kg DM and multiplying by the total land available for grazing gives the total available rangeland feed (Equation 9.3.2):

$$TARF = (2.714*Rain – 100)*agrz \quad (9.3.2)$$

where agrz is the area under grazing.

The feed available from the cultivated land (kg DM) is estimated by assuming that a kilogram of maize grain produces an equivalent of 2.2 kilograms of maize stover (Steinfeld, 1988). It is also assumed that about 50 percent of all the stover produced from the maize crop is fed to the cattle. The total stover feed available by household category is given in Equations 9.3.3.1 and 9.3.3.2:

$$CFLg = armzLg*MZYildLg \quad (9.3.3.1)$$

$$CFSm = armzSm*MZYildSm \quad (9.3.3.2)$$

The total feed available (kg DM) is then the summation of rangeland feed and the feed from the cultivated lands (Equation 9.3.3.3):

$$Hall = TARF + CFLg + CFSm \quad (9.3.3.3)$$

The carrying capacity (CC), - i.e. the maximum number of livestock units (LU) that the rangelands and cultivated lands can support given the level of rainfall, without damaging the environment - is obtained by dividing the total feed available (HAll) by the feed requirements per livestock unit (LU) per year (FeedPerLU). In the model FeedPerLU is assumed to be 8000 kg DM.

$$CC = \frac{HAll}{FeedPerLU} \quad (9.3.4)$$

The recommended stoker days per hectare per year (RSD) is obtained by multiplying CC by 365 days and dividing the resulting product by the sum of the area under grazing and cultivation (Equation 9.3.5):

$$RSD = \frac{365 * CC}{agrz + armzLg + armzSm} \quad (9.3.5)$$

Two variables of the actual stoker days per hectare per year (ASD) are calculated – the opening herd stoker days (OpenHerdSD) (Equation 9.3.6.1) and the closing herd stoker days (ClseHerdSD) (Equation 9.3.6.2). The ASD is obtained by multiplying the total opening or closing herd LU by 365 and dividing by the area under grazing and cultivation:

$$\text{OpenHerdSD} = \frac{365 * \text{CatLUAll}}{\text{agrz} + \text{armzLg} + \text{armzSm}} \qquad (9.3.6.1)$$

$$\text{ClseHerdSD} = \frac{365 * \text{ClseHdLUAll}}{\text{agrz} + \text{armzLg} + \text{armzSm}} \qquad (9.3.6.2)$$

The opening and closing herd ASD are compared to the RSD. If the RSD is at least equal or greater than the ASD then there is no overgrazing, otherwise there is overgrazing. The coefficient ASD/RSD form the basis of capturing the externality effects of overgrazing in the model. If ASD/RSD is greater than 1, then there is overgrazing. Conversely if ASD/RSD is equal to 1 or less then there is no overgrazing.

9.1.6 Milk production constraint

Milk yield (MilkYild) per lactation (liters) is dependent on the level of stocking or grazing pressure i.e. ASD/RSD or OpenHerdSD/RSD. The higher the GP coefficient, the lower is the milk yield (Equation 9.4.1):

$$\text{MilkYild} = \theta_0 - \theta_1 * \frac{\text{OpenHerdSD}}{\text{RSD}} \qquad (9.4.1)$$

Where θ_0 is the milk production function intercept, and

θ_1 is the milk production function slope.

It is assumed that the milk yields for LH and SH households in the same survey site are the same. The total amount of milk produced by each household category is obtained by multiplying the milk yield by the number of milking cows in each household category. To get the value of milk in the model, it is assumed that all the milk produced is sold. Equations 9.4.2.1 and 9.4.2.2 say that the amount of milk sold is less or equal the amount produced.

$$- \text{MilkYild*NMlkCowLg} + \text{MilkSaleLg} <= 0 \qquad (9.4.2.1)$$

$$- \text{MilkYild*NMlkCowSm} + \text{MilkSaleSm} <= 0 \qquad (9.4.2.2)$$

where NMlkCowLg is the number of milking cows for LH households,

NMlkCowSm is the number of milking cows for SH households,

MilkSaleLg is the amount of milk sold by LH households, and

MilkSaleSm is the amount of milk sold by SH households.

9.1.7 Draft power constraint

The number of oxen spans available in any given season per household category is the number of oxen divided by 2. Oxen are required at the end of the year during the rain season for plowing; hence the closing herd number of oxen is used to calculate the number of spans available for cultivation:

$$OxSpanLg = 0.5*NoClseOxenLg \qquad (9.5.1.1)$$

$$OxSpanSm = 0.5*NoClseOxenSm \qquad (9.5.1.2)$$

Where NoClseOxenLg is the closing herd number of oxen for LH households,

NoClseOxenSm is the closing herd number of oxen for SH households,

OxSpanLg is the number of oxen spans available for plowing for LH households, and

OxSpanSm is the number of oxen spans available for plowing for SH households.

A pair of oxen can only be used during 44 days in a year, i.e. from mid November to early January. It is assumed that only SH households hire draft power when they are short of draft power, whilst only LH households can hire-out their draft power. Equation 9.5.2.1 says that the amount of draft power days available (44*OxSpanSm) for SH households plus the amount of draft power days hired in (OxInSm) is greater or equal to the amount of draft power days required to cultivate the area under cropping (armzSm*plowrate). Similarly, for LH households, the amount of draft power days available (44*OxSpanLg) minus the amount of draft power days hired out (OxOutLg) is greater or equal to the amount of draft power days required to cultivate the area under cropping (armzLg*plowrate) (Equation 9.5.2.2). Equation 9.5.3 states that the number of draft days hired-out must equal the number of draft days hired-in.

$$OxInSm + 44*OxSpanSm - armzSm*plowrate >= 0 \qquad (9.5.2.1)$$

$$44*OxSpanLg – OxOutLg – armzLg*plowrate >= 0 \qquad (9.5.2.2)$$

$$OxInSm = OxOutLg \qquad (9.5.3)$$

The number of days required to plow a hectare of land is dependent on GP (Equation 9.5.4). If the GP is high, then a pair of oxen takes more days to plow a hectare. Conversely, if GP is low, the span takes fewer days. The more days it takes to plow a hectare of land negatively affects the planting date and hence maize yields.

$$plowrate = 3 + 1.429*\frac{OpenHerdSD}{RSD} \qquad (9.5.4)$$

9.1.8 Maize production function constraint

Maize yields (kg per ha) are estimated separately for LH and SH households. The maize yields are a function of rainfall, level of nutrient application and grazing pressure (Equation 9.6.1 and 9.6.2):

$$MzYildLg = \mu_1*Rain + \phi_1*ManFertLg - \delta_1*\frac{OpenHerdSD}{RSD} \qquad (9.6.1)$$

$$MzYildSm = \mu_2*Rain + \phi_2*ManFertSm - \delta_2*\frac{OpenHerdSD}{RSD} \qquad (9.6.2)$$

Where MzYildLg is the maize grain yield for LH households,

MzYildSm is the maize grain yield for SH households,

ManFertLg amount of fertilizer and cattle manure applied per ha by LH households,

ManFertSm amount of fertilizer and cattle manure applied per ha by SH households,

μ_1 and μ_2 are the rainfall coefficients for LH and SH households respectively,

ϕ_1 and ϕ_2 are the nutrient coefficients for LH and SH households respectively, and

δ_1 and δ_2 are the grazing pressure coefficients for LH and SH households respectively.

The cattle manure component is derived by assuming that one LU produces about 2.92 kg of nitrogen per year. Hence the amount of cattle manure nitrogen applied per hectare is obtained by multiplying 2.92 by the number of LU per year and dividing by the area under cultivation (Equations 9.6.3.1 and 9.6.3.2). The total amount of nutrients applied is the sum of fertilizer and cattle manure applied per hectare of cultivated land (Equations 9.6.3.3 and 9.6.3.4).

$$ManureLg = 2.92 * \frac{ClseCatLULg + CatLULg}{armzLg * 2} \qquad (9.6.3.1)$$

$$ManureSm = 2.92 * \frac{ClseCatLUSm + CatLUSm}{armzSm * 2} \qquad (9.6.3.2)$$

$$ManFertLg = FertlzLg + ManureLg \qquad (9.6.3.3)$$

$$ManFertSm = FertlzSm + ManureSm \qquad (9.6.3.4)$$

where ManureLg is the amount of manure nitrogen applied per ha of cultivated land for LH households,

ManureSm is the amount of manure nitrogen applied per ha of cultivated land for SH households,

FertlzLg is the amount of fertilizer applied per ha of cultivated land for LH households, and

FertlzSm is the amount of fertilizer applied per ha of cultivated land for SH households,

It is assumed that all the maize produced is sold. This way total maize production is valued. This is presented in Equations 9.6.4.1 and 9.6.4.2:

$$MzYildLg*armzLg - MzSaleLg >= 0 \quad (9.6.4.1)$$

$$MzYildSm*armzSm - MzSaleSm >= 0 \quad (9.6.4.2)$$

9.1.9 Land constraint

Equation 9.7.1 says that the land allocated to growing maize and cattle production should not exceed the total land available in the community (σ_0). Equation 9.7.2 says that the amount of land allocated to maize production by LH households should be less than σ_1 and greater than σ_2. Similarly, Equation 9.7.3 says that the amount of land allocated to maize production by SH households should be less than σ_3 and greater than σ_4.

$$armzLg + armzSm + agrz <= \sigma_0 \quad (9.7.1)$$

$$armzLg <= \sigma_1$$
$$armzLg >= \sigma_2 \quad (9.7.2)$$

$$armzSm <= \sigma_3$$
$$armzSm >= \sigma_4 \quad (9.7.3)$$

9.1.10 Labor constraint

Members of the household – men, women and children contribute labor to activities undertaken by the household with different degrees of specialization. Activities undertaken on the farm that demand labor include crop production, livestock tending, paid farm work at other households within the community, working with hired draft animals, as well as domestic chores around the homestead such as fetching water, fetching fuel wood and timber for domestic use and for sale, laundry, cooking, cleaning and taking care of the infants.

For the purpose of this analysis, households face labour constraints during the cropping season, which is a period of three months (mid-November to mid-February). During other periods of the year, there is slack labour, hence this is not included in the model. Effectively, each working individual has 65 working days during the cropping season. The amount of labour required to work on a hectare of the maize crop is given by Υ_1, Υ_2, and Υ_3 for men, women, and children respectively and the labour days required to attend to a livestock unit (LU) is given by τ_1, τ_2 and τ_3 for men, women, and children respectively. For this model, across all survey sites and for all household categories, it is assumed that men spend 12.5 percent of their available time on domestic activities, whilst women spend 33.3 percent and children only one percent of their time on domestic activities (Equations 9.8.3 and 9.8.4). In the model it is assumed that 50 percent of the labour hired out and/or hire-in is by women and the other 50 percent is by men. It is also assumed that only the LH households hire-in labour whilst the SH households hire-out labour. The amount of labour hired-out (LabOutSm) must equal the amount of labour hired-in (LabInLg). This is represented by Equation 9.8.5. For each class of household members (men, women or children), labour input into all activities must not exceed maximum labour available from the members in the class plus any labour hired in to supplement the class labour (Equations 9.8.1 and 9.8.2).

$$\Upsilon_1 * armzLg + \tau_1 * CatLULg + DomAMenLg - 65 * MenLg - 0.5 * LabInLg <= 0 \quad (9.8.1.1)$$

$$\Upsilon_2 * armzLg + \tau_2 * CatLULg + DomAWmenLg - 65 * WmenLg - 0.5 * LabInLg <= 0 \quad (9.8.1.2)$$

$$\Upsilon_3 * armzLg + DomAChnLg - 12 * ChnLg <= 0 \quad (9.8.1.3)$$

$$\Upsilon_1 * armzSm + \tau_1 * CatLULg + DomAMenSm + 0.5 * LabOutSm - 65 * MenSm <= 0 \quad (9.8.2.1)$$

$$\Upsilon_2 * armzSm + \tau_2 * CatLULg + DomAWmenSm + 0.5 * LabOutSm - 65 * WmenSm <= 0 \quad (9.8.2.2)$$

$$\Upsilon_3 * armzSm + DomAChnSm - 12 * ChnSm <= 0 \quad (9.8.2.3)$$

$$DomAMenLg = 0.125*65*MenLg \quad (9.8.3.1)$$

$$DomAWmenLg = 0.333*65*WmenLg \quad (9.8.3.2)$$

$$DomAChnLg = 0.01*65*ChnLg \quad (9.8.3.3)$$

$$DomAMenSm = 0.125*65*MenSm \quad (9.8.4.1)$$

$$DomAWmenSm = 0.333*65*WmenSm \quad (9.8.4.2)$$

$$DomAChnSm = 0.01*65*ChnSm \quad (9.8.4.3)$$

$$LabInLg = LabOutSm \quad (9.8.5)$$

Where MenLg is the total number of men for LH households,

WmenLg is the total number of women for LH households,

ChnLg is the total number of children LH households,

MenSm is the total number of men for SH households,

WmenSm is the total number of women for SH households,

ChnSm is the total number of children for SH households,

DomAMenLg is men labour days allocated to domestic activities by LH households,

DomAWmenLg is women labour days allocated to domestic activities by LH households,

DomAChnLg is child labour days allocated to domestic activities by LH households,

DomAMenSm is men labour days allocated to domestic activities by SH households,

DomAWmenSm is women labour days allocated to domestic activities by SH households, and

DomAChnSm is child labour days allocated to domestic activities by SH households.

9.1.11 Budget constraint

The availability of income to finance inputs and services at the beginning and during the crop-growing season is a major constraint to most farmers in the survey areas. To reflect this problem a constraint is included in the model requiring that households must have, as a minimum, the cash for producing crops and livestock as well as other requirements such as hiring-in labour or draft services. The budget constraints[26] are presented in Equations 9.9.1 and 9.9.2 for LH and SH households respectively:

$$- C_M*armzLg - C_C*CatLULg - w*LabInLg - GRPrice*TGRDem + BudgetLg >= 0 \quad (9.9.1)$$

$$- C_M*armzSm - C_C*CatLUSm - C_D*OxInSm + BudgetSm >= 0 \quad (9.9.2)$$

where BudgetLg is the budget available for input purchase for LH households, and
BudgetSm is the budget available for input purchase for SH households.

9.1.12 Tradable grazing right constraint

Without tradable grazing rights (TGR), the demand and supply for grazing rights is equal to zero. The model described up to Equation 9.9.2 can then be solved for the scenario without TGR. To model the effects of TGR the estimated community demand function for grazing rights (derived in Section 8.3) for each site is introduced into the model (Equation 9.10.1). The number of grazing rights demanded (TGRDem) decrease with an increase in the price for grazing rights (GRPrice). The grazing rights system is demand driven and at equilibrium what is demanded is equal to what is supplied (TGRSuply) (Equation 9.10.2).

$$TGRDem = \upsilon_0 - \upsilon_1*GRPrice \quad (9.10.1)$$

$$TGRSuply = TGRDem \quad (9.10.2)$$

[26] BudgetLg and BudgetSm are computed from the household surveys data.

where υ_0 is the intercept of the demand function, and

υ_1 is the slope of the demand function.

Since the grazing rights systems modeled is the one of grand-fathering, the potential number of grazing rights to be demanded (GRPotDem) is calculated as the difference between the cattle herd size for LH households (CatLuLg) minus the number of LH households in the community (NoHHDLg) multiplied by the number of grazing shares permissible per household, i.e. (CC/TotalHHD) (Equation 9.10.3). This is the number of cattle that do not get "free" grazing under the system of grazing rights. The number of grazing rights per household is dependent on the carrying capacity.

$$\text{GRPotDem} = \text{CatLuLg} - \text{NoHHDLg}^{*}\frac{\text{CC}}{\text{TotalHHD}} \qquad (9.10.3)$$

where TotalHHD is the total number of households in the community.

Given the grazing right price, the number of cattle for which grazing is not secured and hence are destocked (CatDestock) is given by Equation 9.10.4. With TGR, the number of cattle de-stocked is equal the cattle sales by LH households. So cattle off-take by LH households (Equation 9.2.7.7) becomes Equation 9.10.5 where the number of cattle sold is equal to the number of cattle de-stocked.

$$\text{CatDestock} = \text{GRPotDem} - \text{TGRDem} \qquad (9.10.4)$$

$$\text{CatSaleLg} = \text{CatDestock} \qquad (9.10.5)$$

9.1.13 Rainfall

Rainfall is the driving variable in the model. A rainfall distribution for each site over a 45-year period was obtained (see Section 2.5.1) and the corresponding probabilities for each rainfall level occurring. As such, for variables that are rainfall dependant, i.e. rangeland productivity, cattle herd productivity, crop (maize) productivity, and gross margins from agricultural production with and without TGR, the expected values are the ones presented given the probability distribution of rainfall for a given study site. For example, the maize yields for any study site is given by:

$$\varepsilon(\text{MZY}) = \sum_{i=1}^{n} \text{MZY}^{i} * \text{Pr}^{i}$$

where ε (MZY) is the expected maize yield,

MZY^{i} is the estimated maize yield under rainfall level **i**, and

Pr^{i} is the probability of rainfall level **i** occurring.

Because of this formulation, no sensitivity analysis of the results is performed with respect to rainfall levels. The parameters of the exogenous variables and constraints to the model is presented is presented in Table 9.1. The full recursive bio-economic LP models for each study site for the base year are presented in Annex III.

Table 9.1: Linear Programming Model Exogenous Variables and Constraints Parameters

Variable	Variable Description	Nerutanga	Gaza	Chiduku	Matsika
Objective Function Parameters					
C_M	Cost of producing maize per ha (USD)	14.68	11.4	16.29	17.36
C_C	Annual cost of keeping cattle per livestock unit (USD)	7.88	11.7	9.40	9.40
W	Local community wage rate per day (USD)	0.44	0.44	0.44	0.44
C_D	Price of draft power per ha (USD)	7.38	8.43	5.80	7.91
P_{mz}	Selling price for maize per kilogram (USD)	0.09	0.09	0.09	0.09
P_{cat}	Price per unit cattle sold (USD)	117.60	90.78	114.47	135.63
P_{mk}	Price per liter of milk (USD)	0.42	0.63	0.79	0.66
Cattle Herd Dynamics Parameters					
CatLg (α_1)	Number of cattle owned by LH households	226	318	363	281
CatSm (α_2)	Number of cattle owned by SH households	201	69	372	145
PercentCow (β)	Percent cows in cattle herd	33.6	36.5	27.2	32.7
PercentOx (γ)	Percent oxen in cattle herd	29.2	30.2	33.8	28.2
CullratePc (φ)	Offtake (culling) rate	3.7	5.5	5.4	7.2
Fertilizer Use Parameters					
FertlzLg	Amount of fertilizer applied per ha of cultivated land for LH households	63.17	85.47	106.33	96.56
FertlzSm	Amount of fertilizer applied per ha of cultivated land for SH households	45.33	89.68	83.78	95.46
Land Allocation Constraints					
σ_0	Total land available in the community (ha)	1575	1607	2512.5	1792.5
rmzLg	Land allocated to maize production by LH households	181.3	207.9	254.23	179.07
armzSm	Land allocated to maize production by SH households (upper bound)	80.06	146.88	129.71	117.17
Demographic Parameters					
	Household size	3.8	4.4	4.7	4.1
	Number of LH households	49	74	67	45
	Number of SH households	83	88	176	116
	Percent household members men	25.0	25.0	25.0	25.0
	Percent household members women	33.3	33.3	33.3	33.3
	Percent household members children	41.7	41.7	41.7	41.7
Budget Constraints					
BudgetLg	Budget available for input purchase for LH households	3000	3425	4910	3425
BudgetSm	Budget available for input purchase for SH households	2700	2890	4480	2890

9.2 Results

9.2.1 Base results

The base (Year 0) results of the model without tradable grazing rights are presented in Table 9.2. Also included in the table are comparable results from the household survey data. On average, the model under-estimates: (i) the opening cattle herd sizes by about 6 percent; (ii) the area under maize production by LH and SH households by 53 percent and 14 percent respectively; (iii) the area under grazing by 19 percent; (iv) calf mortality and adult cattle mortality by 0.1 percent and 2.3 percent respectively; (v) milk yields by 4 percent for LH households and by 6 percent for SH households; and (iv) milk yields by 14 percent. The model over-estimates cattle off-take and calving rates by 1.2 percent and 12.5 percent respectively. The disparity between model base results and survey results is more pronounced in land allocation between maize and grazing, otherwise the LP model specification seem to satisfactorily represent the survey sites cattle and crop production activities.

Table 9.2: Linear Programming Base Results and Comparable Survey Results

Variable	Nerutanga		Gaza		Chiduku		Matsika	
	LP Model	Survey	LP Model	Survey	LP Model	Survey	LP Model	Survey
Opening Herd								
LH Households (LUs)	160	180.8	221	254.4	290	290.4	224	224.8
SH Households (LUs)	142	160.8	48	55.2	298	297.6	116	116
Cattle Herd Performance Parameters								
Off-take rate (%)	4.4	3.7	6.7	5.5	6.5	5.4	8.9	7.2
Calving rate (%)	48.1	33.6	41.9	26.7	46.9	47.1	54.3	33.8
Calf mortality (%)	8.6	10.8	9.5	10.0	11.3	10.9	9.6	7.7
Adult mortality (%)	4.3	16.3	4.6	0.9	5.5	3.3	4.8	8.0
Land Allocations								
Maize area, LH HH (ha)	67.6	181.3	116.2	207.9	133.8	254.23	73.0	179.07
Maize area, SH HH (ha)	71.2	80.06	118.7	146.88	103.3	129.71	112.7	117.17
Area under grazing (ha)	1262.0	1575	1163.1	1607	2159.7	2512.5	1496.3	1792.5
Maize Yield (kg ha^{-1})								
LH Households	1125.1	1244	603.0	647	1234.8	1248	1728.5	1692
SH Households	907.9	1017	428.3	552	1065.6	967	1590.0	1634
Milk Yield (Liters per	102	130	134	157	156	175	220	238

lactation per cow)

HH - households

The potential impact of TGR under constraint will be assessed using the following criteria:

- Cost-effectiveness,
- Distributional impacts,
- Grazing pressure, and
- Food self-sufficiency.

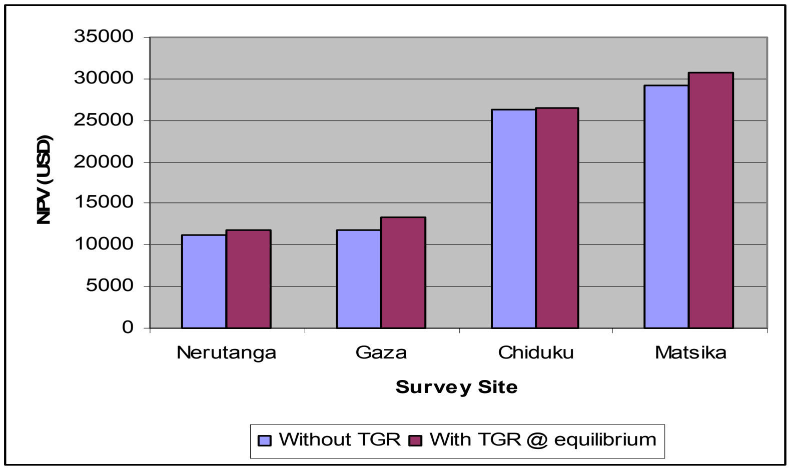
All assessments are done by comparing the results under TGR at equilibrium and the status quo.

9.2.2 Cost-effectiveness of TGR

The measure for cost-effectiveness used for analysis is the net present value (NPV). The gross margin per year over the five-year analysis period is discounted at eight (8) percent and the sum of the discounted cash-flows gives the NPV. The opportunity cost of capital in real terms for Africa is estimated at between 8 and 15 percent and a common choice is 12% (Gittinger, 1982). The 8 percent discount rate is used not to heavily discount the future benefits that arise from the conservation of the natural rangelands. The higher the NPV per given scenario, the more attractive the scenario. The net present values are calculated for the community as a whole, and then disaggregated for large (LH) and small herd (SH) households.

Figure 9.2 shows the overall NPV with and without TGR. The figure shows that irrespective of the survey site, at community level, grazing management under TGR is likely to be more cost-effective than grazing management under the status quo. This is shown by the higher NPV with TGR and the lower NPV without TGR. Overall, the percentage change in the NPV increases from Chiduku (about 1 percent), Nerutanga (about 5 percent), Matsika (about 5 percent) and Gaza (about 13 percent) (Figure 9.3).

Figure 9.2: Expected Overall NPV With and Without TGR by Survey Site

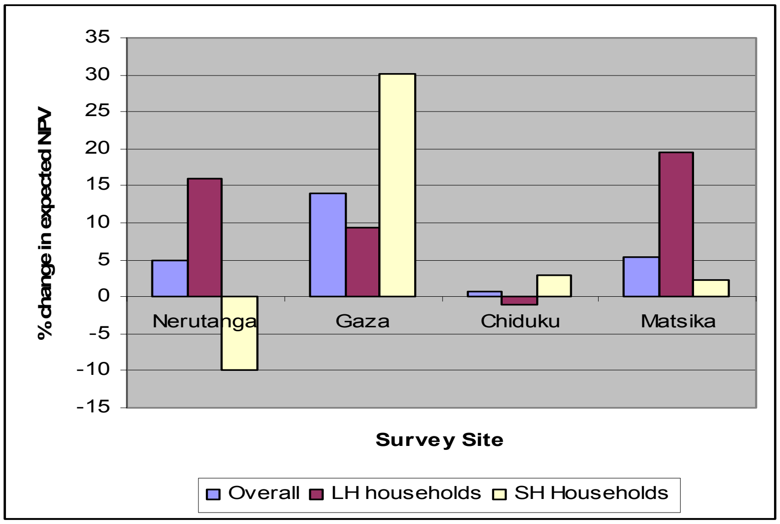


An analysis of the overall GM shows that during the early time periods, the GM with TGR is higher than without TGR. By the end of year 4, the GMs with and without TGR are similar. Thus, the higher returns with TGR are due to the benefits realized during the early periods of implementation. These are the benefits that result from the initial high cattle off-take with TGR as LH are not able to secure grazing rights for all their cattle.

9.2.3 Income Distribution with TGR

An analysis of the NPVs by household categories shows that some household categories are likely to lose with the implementation of TGR. These are SH households in Nerutanga and LH households in Chiduku who have negative percentage changes in the NPV with TGR (Figure 9.3). Across all survey sites, except in Gaza, the percentage increase in the NPV of the GM with TGR is higher for LH households. In Gaza, the percentage change in NPV is higher for SH households.

Figure 9.3: Percentage Change in the Expected NPV with TGR at Equilibrium Price by Household Category by Survey Site



To further assess the distributive impact of TGR the percentage gross margin (GM) accruing to LH and SH households with and without TGR is compared. The results are presented in Table 9.3. The percentage income from agricultural production accruing to SH households with TGR for Nerutanga decrease by about 6 percent and for Matsika by about 4 percent. For Chiduku the percentage income from agricultural production accruing to SH increase slightly (0.9 percent) with TGR. For Gaza the percentage income accruing to SH households increases by about 3 percent.

Table 9.3: Five-Year Average Percent GM With and Without TGR accruing to SH households by Survey Site

	Nerutanga	Gaza	Chiduku	Matsika
Without TGR	44.9	22.8	43.8	52.5
With TGR at equilibrium	38.8	26.1	44.7	48.6

Figure 9.4 shows that on average, the GM per household is higher with TGR for both LH and SH households across the survey sites, except for LH households in Chiduku and SH households in Nerutanga. Table 9.5 shows that the highest increase in the GM per household is for SH households in Gaza and lowest for SH households in Chiduku. The percentage increase in the GM per household with TGR is similar between Nerutanga and Matsika. The results of Table 9.4 suggest that the implementation of TGR results in an improvement of income for LH households in the relatively wet regions, Nerutanga and Matsika, and for SH households in the relatively dry areas of Gaza and Chiduku.

Figure 9.4: Five-Year Average GM per Household (USD) by Household Category by Survey Site

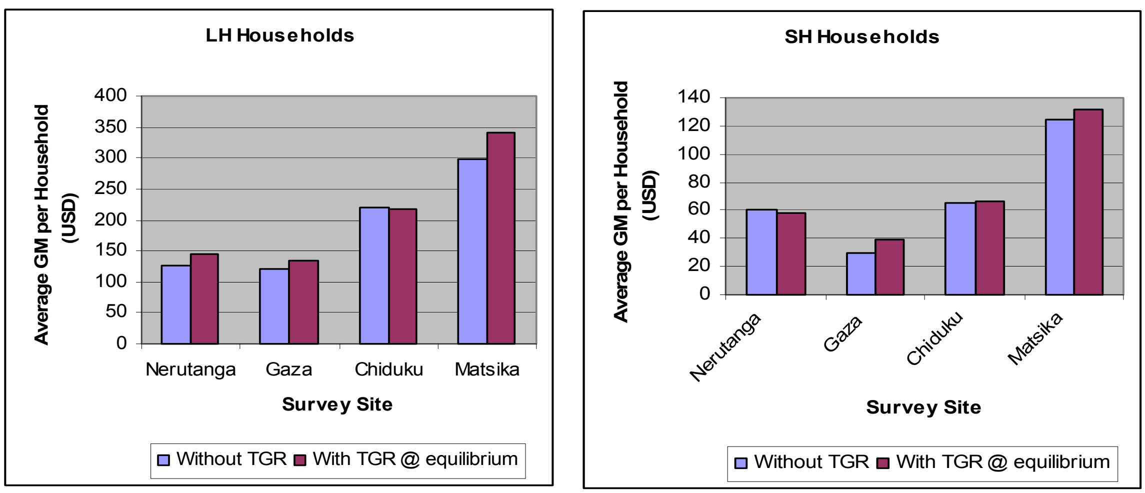


Table 9.4: Percentage Change of the Average GM per Household with TGR at Equilibrium by Household Category by Survey Site

Household Category	Nerutanga	Gaza	Chiduku	Matsika
LH Households	15.9	9.8	-0.9	15.2
SH Households	-3.3	30.0	3.1	5.6

9.2.4 Grazing Pressure

The impact of TGR on the environment, i.e. on the rangelands is captured through a grazing pressure index, the actual stoker days per ha per year divided by the recommended stoker days per hectare per year, i.e. ASD/RSD. An index of at least 1 means there is overstocking whilst an index of less than 1 means there is no overstocking.

The results show that using TGR for grazing control may result in reduced grazing pressure (Figure 9.5). On average, across all survey sites, the grazing pressure is lower with TGR than the status quo. Figure 9.6 shows that the greatest decrease in GP is in Nerutanga followed by Gaza. The least improvement in GP is in Chiduku. However, in Gaza, Chiduku and Matsika, the decrease in grazing pressure at the equilibrium price for TGR is not large enough to graze within the carrying capacity of the rangelands (Figure 9.7). The results show that whilst Nerutanga starts-off not overgrazed in the medium-run if no grazing control mechanisms are put in place, the result is overgrazing.

Figure 9.5: Five-Year Average Grazing Pressure Index With and Without TGR by Survey Site

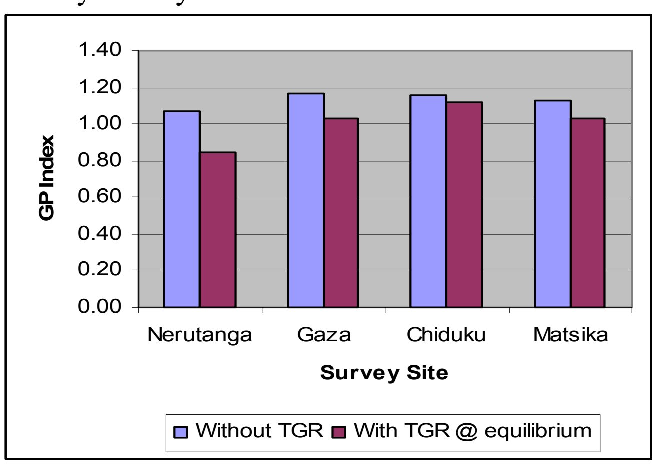


Figure 9.6: Percentage Change in Average GP with TGR at Equilibrium by Survey Site

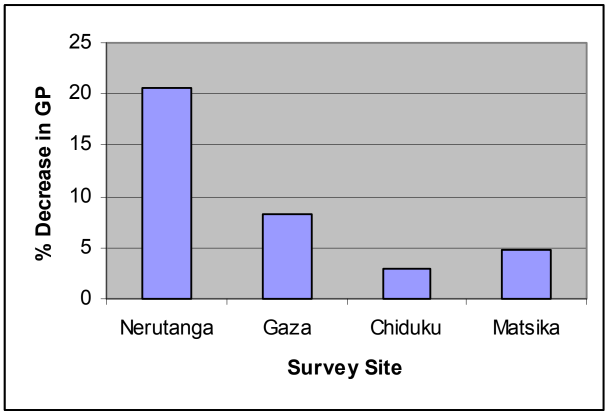
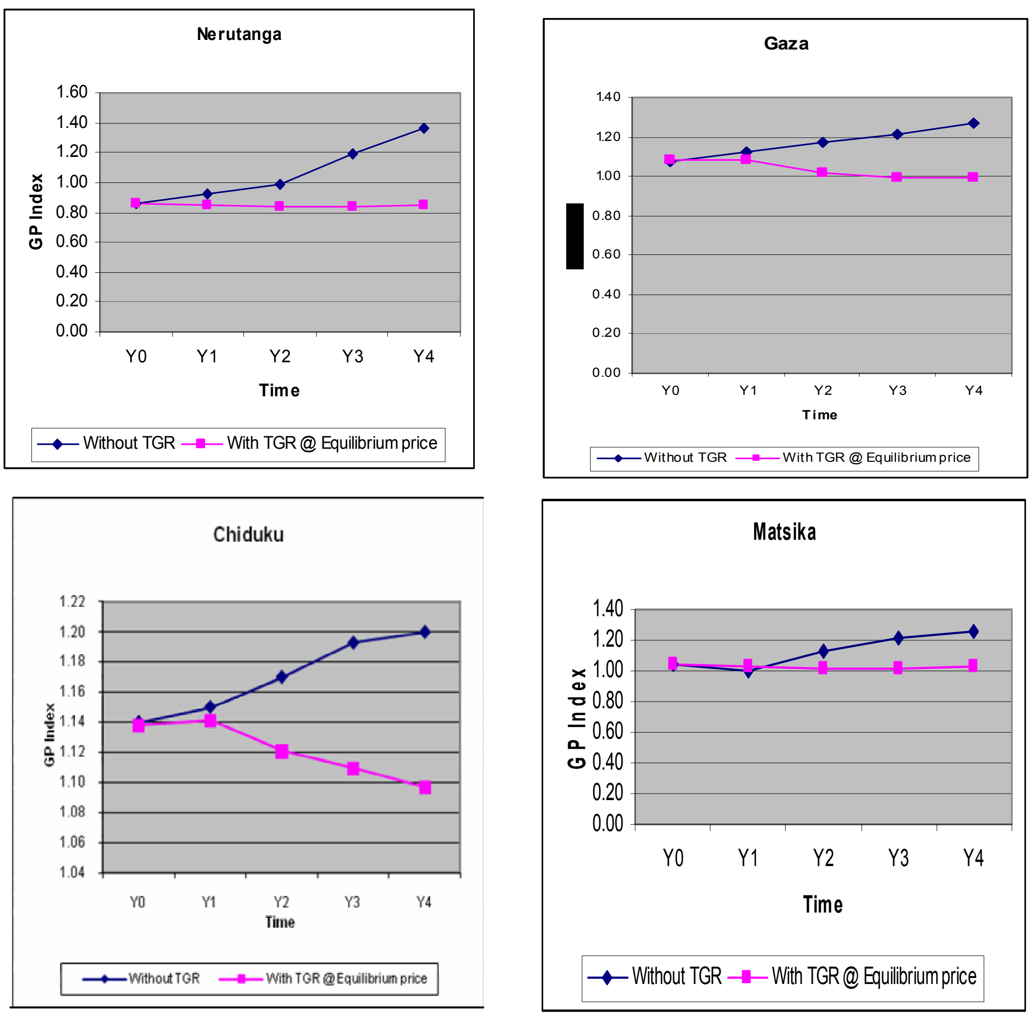


Figure 9.7: Grazing Pressure With and Without TGR over Time by Survey Site



9.2.5 Food Self-Sufficiency

This section analyses the extent to which communities are likely to be food self-sufficient with the implementation of TGR. Food self-sufficiency occurs when a household or community can meet their food requirements from own production.

The minimum amount of grain required to sustain a healthy life for an adult male is estimated at 155 kgs per year (Rook, 1994; SADCC/FAO, 1992). If an adult male represents an adult equivalent, then the total number of adult equivalents (AE) for each household category per survey site can be calculated. Given the total adult equivalents (TAE) per household category within a community and the grain requirements per AE, then the minimum grain requirements for that household category per year can be calculated as:

$$TAE*155$$

Given the total grain production (GRAINP) per household category with and without TGR, the food self-sufficient index (FSSI) can be calculated as:

$$\frac{GRAINP}{TAE*155}$$

A FSSI of at least 1 means that the household category produces enough grain to meet grain requirements until the next harvest, whilst an index of less than 1 means the household category does not produce enough grain to last till the next harvest.

With or without TGR, household categories across all survey sites are on average grain self-sufficient (Figure 9.8). An analysis by household category shows that on average and in the medium term, TGR are likely to result in a decrease in food self-sufficiency for LH households in Gaza and Chiduku. An analysis for SH households shows that across all survey sites, except in Chiduku, the level of food self-sufficiency is at least 4 percent higher with TGR than under the status quo (Figure 9.9).

Figure 9.8: Five-Year Average Grain Self-Sufficiency Index With and Without TGR by Household Category by Survey Site

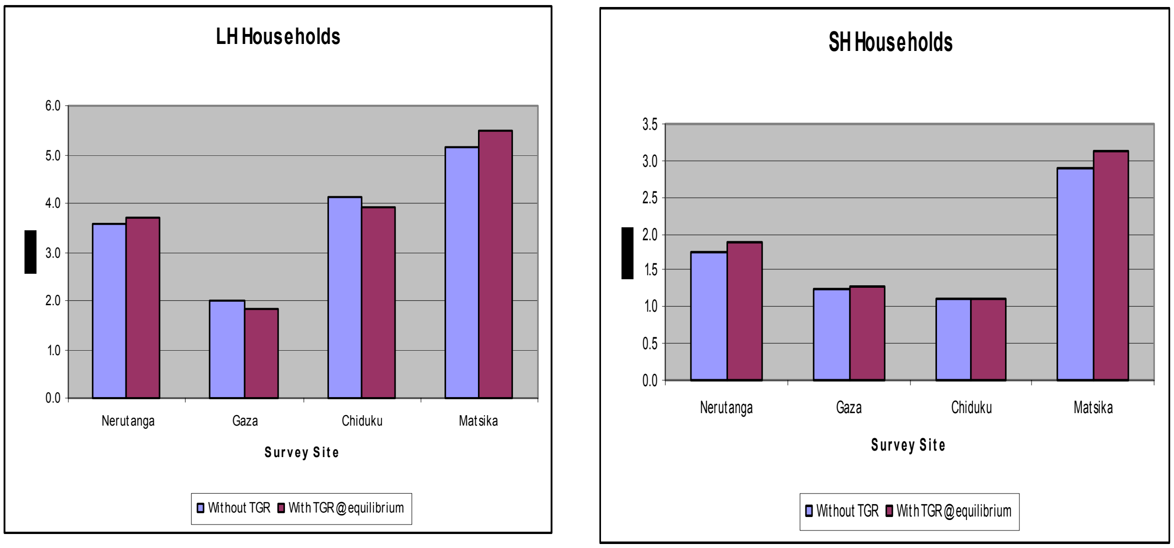
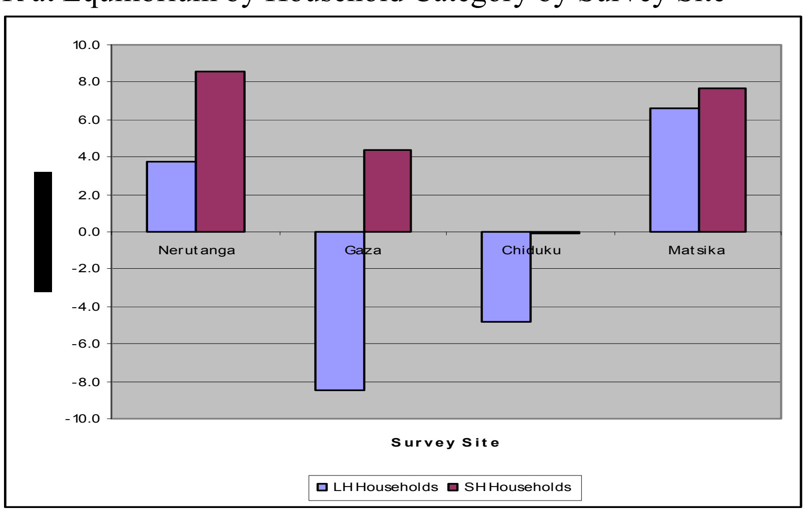


Figure 9.9: Percentage Change in the Average Grain Self-Sufficiency Index with TGR at Equilibrium by Household Category by Survey Site



9.3 Summary

This Chapter developed a recursive bio-economic linear programming model to assess the potential impacts of using TGR for grazing control under the constraints of land, income, and labor that communal farmers face. A cost-effective analysis of using TGR for grazing control shows that TGR are more cost-effective than the status quo. This is shown by the higher NPV with TGR. The higher returns with TGR are mainly due to the benefits of de-stocking during the early periods of implementation as LH are not able to secure grazing rights for some of their cattle.

Despite the cost-effectiveness of TGR at the community level, SH households in Nerutanga and LH households in Chiduku are likely to experience lower NPVs with TGR. Except in Gaza, the percentage increase in the NPV with TGR is higher for LH households. In Gaza, the percentage increase in NPV is higher for SH households.

Generally, grazing control with TGR would result in a higher per capita household income than without TGR. Whilst TGR are likely to result in increased agricultural income, the distributive impact of the policy is likely to be in favor of LH households in the relatively wet regions, i.e. Nerutanga and Matsika and SH households in the relatively dry regions, i.e. Chiduku and Gaza.

An analysis of the likely impacts of TGR on grazing pressure show that using TGR for grazing control may result in reduced grazing pressure in the short term. However, in Gaza, Chiduku and Matsika, TGR at the equilibrium price are not sufficient to reduce GP to within the carrying capacity of the rangelands.

With or without TGR, household categories across all survey sites are on average grain self-sufficient. TGR are likely to result in a decrease in food self-sufficiency for LH households in Gaza and Chiduku. The results for SH households show that except in Chiduku, the level of food self-sufficiency is at least 4 percent higher with TGR than under the status quo.

CHAPTER X: STUDY SUMMARY, CONCLUSIONS, POLICY IMPLICATIONS AND AREAS OF FURTHER RESEARCH

10.0 INTRODUCTION

The problem motivating this study was the perceived degradation of grazing resources in the communal areas of Zimbabwe. The poor sustainability in grazing resource use has been manifested in the low crop and livestock productivity, rangeland degradation due to overgrazing and lack of investment in rangeland improvement. As such, communal area households are unable to maximize on the value of the benefits they obtain from their grazing resources. Altenative grazing management options are therefore explored for the improved and sustainable management of grazing resources in the communal areas of Zimbabwe.

Using the underlying assumption that grazing resources in the communal areas of Zimbabwe are open access and overgrazed, the specific objectives of the research were to: adapt pollution abatement control theory to grazing rights; assess household preference of alternative grazing management policy options; assess household attitudes towards use of TGR for grazing resource control, and assess the efficiency, equity, environmental impact and food security implications of adopting TGR using a recursive bio-economic linear programming model.

This Chapter is organized as follows. Section 10.1 provides a summary of the key findings of the study. Study implications for policy and development planning are highlighted in Section 10.2. The chapter concludes with an outline of areas of further research (Section 10.3).

10.1 Summary of Study Major Conclusions

10.1.1 Adapting Pollution control theory to grazing control

Adapting from pollution abatement theory, a comparative static analysis of the use of TGR for grazing resource management versus the setting of standards and use of taxes using the criteria of cost-effectiveness, equity, dynamic efficiency and enforceability concludes that TGR are a better instrument to use. The use of standards to achieve the optimal level of grazing is not cost-effective because the MAC are not equal for all herders. With a tax system, there is no element of compulsion as with the standard and it is in the interest of the herders to graze at the optimal level. At the optimal level the analysis shows that the MAC are equal for all herders under a tax system. However, taxes have the disadvantage of creating a double burden for herders. They must not only pay the MAC of grazing but they must still pay a tax on the remaining grazing livestock. The grazing right system is shown to be cost-effective; the MAC is equal for all herders. Assuming that the initial allocation of grazing rights is free – i.e. grazing permits are grand-fathered, the comparative analysis results shows that, theoretically, the use of tradable grazing rights for grazing control is more cost effective than both standards and the tax system.

Unlike standards and taxes, TGR, theoretically are more equitable, assuming that the initial allocation of permits is free. With the trade in grazing right permits those households who would not benefit directly from grazing resource use would derive income from trading in grazing permits. However, a grand-fathering system can discriminate against new entrants once the permits are distributed. One way of overcoming the problem of new entrants would be to distribute the grazing permits every year and not over some longer period of time. If an auction system is used to allocate the initial grazing permits the herders have to pay the auction price for their first allocation of permits, and this represents a financial burden on herders equal to the burden under a tax system, affecting their competitiveness.

An advantage of an open grazing right market is that it gives the regulatory body – be it the state or a local authority - the opportunity to intervene and buy permits if it decided that rangeland conditions needs to be improved, thus inducing dynamic efficiency in grazing resource use. Dynamic efficiency in grazing control could result from farmers practicing zero grazing. This could be achieved by producing fodder for the cattle or if farmers start supplementing their cattle feed requirements with feed concentrates.

10.1.2 Communal grazing resources are open access and overgrazed

To test the main assumption underlying the motivation for alternative grazing management policy rather than the status quo, an analysis was made to assess whether grazing resources in the communal areas of Zimbabwe are open access, overgrazed or both. To test the hypothesis that communal area rangelands are overgrazed, stoker days per ha per year are used as a measure of grazing pressure. Comparing the actual stoker days (ASD) and the recommended stoker days (RSD) per survey site over time shows that Nerutanga and Matsika are not yet over grazed. However, in Chiduku and Nerutanga overgrazing occurs during periods of low rainfall. Gaza and Chiduku have been overgrazed since the 1980s. Overgrazing is greatest in Chiduku. On average, Gaza is overstocked by about 9 percent and Chiduku by about 15 percent during the 1980s. During the 1990s, Gaza is overstocked by 29 percent whilst Chiduku is overstocked by 35 percent. Hence, it can be concluded that Chiduku and Gaza are overgrazed.

An assessment of the perceived overgrazing in the study sites shows that at least 41 percent of the households in Nerutanga to 68 percent of the households in Matsika perceive their grazing resources to be moderately to seriously overgrazed. The major reasons for the perceived overgrazing are, in order of importance: there is little land for grazing, households do not sell their cattle, and households from other communities graze on local rangelands. Consequently, due to overgrazing, across all survey sites, from 50 percent of the households in Chiduku to 80 percent of the households in Gaza perceive that milk, draft power and crop productivity has been declining over time.

Whilst cattle are individually owned, all grazing land is communally owned with little control over its use, thus making any improvement measures uneconomic to implement under the current grazing practices. No formal permission is required for putting livestock to pasture as long as one is resident in the village controlling the pasture. Lack of well-defined and exclusive property rights, though not the single cause, is a major contributor to the overgrazing in the survey sites. This is shown by at most 14 percent of the households in Gaza, Chiduku and Matsika indicating that there are boundary rules in grazing resource use.

There may be exclusion and boundary rules in Nerutanga as 50 percent of the households indicate that there are boundary rules to grazing resource use whilst 40 percent indicated that there are some monitoring of grazing resource use.

Across all survey sites, the boundary rules, though weak, are of two forms: (i) within community boundary rules, and (ii) between community boundary rules. Within the community, during the summer season, households are not allowed to graze near the cropped fields of other households, to prevent livestock from destroying crops. Between the communities, households are not supposed to graze their livestock on grazing designated to other communities. However, an analysis of the degree of compliance with inter-community boundary rules shows that except in Nerutanga (where only up to 10 percent of the households graze outside their community boundaries), there is weak inter-community boundary or exclusion rules. From 70 percent of the households in Gaza to 90 percent of the households in Matsika graze their livestock outside their designated rangelands.

These results suggest that households know that there are boundaries for grazing resource use only that the boundary rules are not enforced and hence the high frequency of households grazing outside own communities. Because there are no exclusion rules and enforcement mechanisms for grazing resource management, it is concluded that grazing resources in the communal areas are open access. However, some of the grazing resources are not yet overgrazed.

10.1.3 Household preference of alternative grazing management policy options

Since TGR is a policy whose concepts are new to communal grazing management, it is important to assess the farmers' perceptions and attitudes towards the policy. To be workable, the grazing resource use policies must pass the test of institutional acceptability; they must be politically acceptable and not conflict with accepted customs and traditions. An analysis of the preferred grazing management options was conducted for: the individualization of grazing, formation of grazing schemes, community based initiatives, TGR, taxing all cattle, taxing only cattle above four, fodder production and the status quo. Grazing schemes and TGR form a clear camp of opposition to the status quo than other grazing management options.

Empirical results show that TGR are the third most preferred grazing management policy after the individualization of grazing and the formation of grazing schemes. TGR and the formation of grazing schemes form a clear coalition camp than other grazing management options. Households are willing to pay (WTP) and willing to accept (WTA) for TGR and hence it is possible to establish markets for grazing rights. Hence, tradable grazing rights (TGR) are proposed as a potential policy for grazing resource management in the communal areas.

TGR are the third (43.3 percent of the households across survey sites) most preferred grazing policy after the individualization of grazing (67 percent) and grazing schemes (49.5 percent). The least preferred options are fodder production (17 percent) and the status quo (20 percent). TGR are clearly supported by households with few or no cattle and by households in high potential agricultural regions and are opposed households with relatively large cattle herds. TGR are preferred because grazing shares are given for free and equally to both cattle and non-cattle owners. In this case non-cattle owners benefit directly from selling their grazing rights to cattle owners, an aspect which is currently non-existent. The main reason for opposing TGR is that if the grazing quota for a particular specified time period is met, cattle without grazing rights are sold (unless some form of dynamic efficiency is adopted) – unlike the IOG and GS options where there is no "compulsory de-stocking".

The maximum likelihood estimates show that farmers' preferences of grazing policies are fairly stable. No elasticities or marginal probabilities are greater than one. Only dramatic changes in the socio-economic circumstances or farmer characteristics will alter the support or non-support for the different grazing policies. Thus, once the implementation of a grazing policy, based on farmer preferences, is adopted, the chances of its success are high as farmers may not easily switch their preference to other policies.

The factors that significantly affect the support for TGR are the number of cattle owned and agro-ecological region. Households with large cattle herds are more likely to oppose TGR.

Conversely, households with small cattle herds or have no cattle at all are more likely to support TGR. A 10 percent increase in the number of cattle owned would reduce the probability of support by 1.1 percent. The opposition to TGR by large stock owners results from the fear of de-stocking which might occur if demand for grazing rights exceeds the carrying capacity of the veld. Households in NR IV are more likely to oppose tradable grazing rights than households in NR II. A 10 percent increase in the proportion of farmers in NR IV would decrease the probability of support for TGR by 1.8 percent.

The factors that significantly affect the support or non-support of the current grazing practice are farm size, residence in areas designated for grazing, and agro-ecological region. As farm size increases, the probability of support for the current grazing practice increases. A 10 percent increase in farm size increases the probability of support of the status quo by 3.5 percent. Households with large holdings may be able to supplement grazing from their own land. Thus, the need to change the status quo is not pressing for these households.

10.1.4 Household WTP and WTA for TGR

To test the hypothesis that households are willint to pay or willing accept for TGR, an analysis of household willingness to pay (WTP) and willingness to accept (WTA) for grazing rights was attempted. An analysis of household WTP for TGR enabled the identification of the households who are likely to de-stock with the implementation of TGR. Households with low maximum willingness to pay (MWTP) are likely to de-stock with the introduction of TGR because they cannot afford to pay for grazing permits. An analysis of WTA for TGR enabled the identification of household categories that are likely to benefit from the trade in grazing rights. *Ceteris paribus*, households with low maximum willingness to accept (MWTA) are likely to participate and benefit in the trade of grazing rights than households with high MWTA.

An analysis of the MWTP for grazing rights for the households with relatively large herds (LH households) by survey site shows that on average, households in Chiduku have the highest MWTP followed by households in Matsika. Households in Gaza have the lowest mean MWTP. Of the LH households, poor households in Gaza, Chiduku and Matsika;

households whose heads did not attend school in Gaza and Matsika; and widow headed households in Chiduku and Matsika are not likely to afford to pay for grazing rights hence they are likely to de-stock first with the introduction of TGR. Of the SH households, all household categories in Nerutanga, Gaza, and Chiduku are likely to benefit from trading grazing rights. In Matsika, the household categories likely to benefit from the trade of grazing rights are poor households and households whose heads did not attend school.

Of those households with relatively small cattle herds (SH households) across all survey sites, at least 89 percent are WTA payment for grazing rights. The percentage households not WTA payment for grazing rights is higher in Nerutanga and Gaza than in Chiduku and Matsika. The main reason for not WTA for grazing rights is that they are already benefiting indirectly from the use of grazing resources through those with large cattle herds. These benefits include the availability of draft power, milk, and manure. They are concerned that if they charge for grazing rights they may no longer receive these benefits. Given that households are LH households are WTP and SH households are WTA for TGR, the analysis concludes that it is possible to form a market grazing rights in the communal areas of Zimbabwe.

10.1.5 Preferred mode of payment for TGR

To test the hypothesis that the preferred modes of payment are similar between LH and SH households, an analysis is made of the preferred mode of payment for TGR. The determination of the mode of payment for TGR is important when designing the intervention strategy for TGR. TGR can be paid for in cash or by plowing. If there is a disparity in the preferred mode of payment between LH households and SH households, then it may be difficult to establish an efficient market in grazing permits. On one hand, at least 55 percent of the LH households in Gaza, Nerutanga and Matsika prefer plowing as the mode of payment. The percent of LH households preferring plowing as the mode of payment is 45 percent in Chiduku. On the other hand, at least 70 percent of the SH households in Nerutanga and Gaza prefer plowing as the mode of payment for grazing permits whilst the percentage is at most 36 percent in Chiduku and Matsika. A substantial percentage of households in Nerutanga and Matsika vidcos prefer other modes of payment for grazing rights like weeding or no payment at all.

Whilst the results show that a combination of plowing and cash as the modes of payment for grazing permits, respective communities will need to organize meetings to discuss and agree on the mode of payment they would use in their area. If the community meeting settles on plowing as the mode of payment, then they would need to agree on the unit of land that would be equivalent to the value of a grazing permit. Alternatively, households would need to negotiate on a one-to-one basis on the preferred mode of payment.

10.1.6 Potential impact of TGR on agricultural productivity

To test the hypothesis that TGR are likely to result in improved agricultural productivity, based on the household MWTP and MWTA for grazing rights, demand and supply functions for grazing rights were derived. Using the estimated grazing pressure at the equilibrium price for grazing rights, cattle herd performance parameters, plowing rates, maize and milk yield functions were estimated.

An assessment of the potential impact of TGR on cattle herd performance shows that Matsika has the lowest improvement in the herd performance with TGR with 0.26, 0.11 and 1.19 percentage point increases in the calf mortality rate, the adult cattle mortality rate and the calving rate respectively. Gaza has the highest improvement in the herd performance with 2.03, 0.79 and 9.05 percentage point increases in the calf mortality rate, the adult cattle mortality rate and the calving rate respectively. The results seem to indicate that the impact of TGR on cattle herd performance is likely to be positive and greatest in the dry and overstocked regions and the least in the relatively wet regions.

An analysis of the percentage decrease in the number of days to plow a hectare of land with TGR compared to the status quo shows a 12.4 percent, 2.8 percent, 2 percent, and 1.8 percent decrease in Gaza, Chiduku, Nerutanga, and Matsika respectively.

Comparing the maize yields with TGR at the equilibrium price level for grazing rights and the status quo shows the following: (i) maize yields for LH households in Chiduku and Gaza increase by 1 percent and 4 percent respectively, (ii) there are no changes in maize yields for LH households in Matsika, (iii) maize yields in Nerutanga decrease by about 0.3 percent for LH households, (iv) maize yields for SH households increase by 0.4, 1.9 and 9.1 percent in Matsika, Chiduku and Gaza respectively, and there are no changes in maize yields for SH households in Nerutanga. The results suggest that the impact of TGR on maize yields is likely to be very small; with the relatively dry agro-ecological regions having higher maize yield impacts.

The highest improvement in milk yields is likely to be in Nerutanga (10 percent). The lowest yield improvement is likely to be in Matsika (2.5 percent). Gaza and Chiduku are likely to have milk yield improvements of 6.4 and 4.6 percent respectively. Thus, the highest milk yield improvements with TGR are likely to be in relatively wet regions with relatively low grazing pressure whilst the lowest improvements are likely to be in the wet regions with relatively high grazing pressure.

10.1.7 Cost-effectiveness, equity, environmental and food security impact of TGR

Using a recursive bio-economic linear programming model, the cost-effectiveness, equity, environmental and food security impacts of TGR are compared to the status quo. Using TGR for grazing control is more cost-effective than the status quo. This is shown by the higher expected NPV with TGR. The community NPV with TGR at the equilibrium price is higher by about 13, 5, 5 and 1 percent in Gaza, Nerutanga, Matsika, and Chiduku respectively. The higher returns with TGR are mainly due to the initial high cattle off-take by the large-herd (LH) households who are not able to secure grazing rights for their cattle.

An analysis of the likely impacts of TGR on grazing pressure (GP) showed that using TGR for grazing control may result in reduced grazing pressure depending on the weather conditions. Under normal and favorable rainfall conditions, the implementation of TGR at equilibrium is likely to reduce the level of grazing pressure by about 21 percent, 8 percent, 3 percent and 5 percent in Nerutanga, Gaza, Chiduku and Matsika respectively. In the medium term, the GP is likely to reduce to within the carrying capacity of the rangelands in Nerutanga only. However, in Gaza, Chiduku and Matsika, TGR at the equilibrium price are not sufficient to reduce GP to within the carrying capacity of the rangelands. Under extremely harsh weather conditions, on their own, TGR may not be effective in controlling overstocking.

Using a food self-sufficiency index (FSSI), the results show that with or without TGR, household categories across all survey sites are on average grain self-sufficient. An analysis by household category shows that on average and in the medium term, TGR are likely to result in a decrease in food self-sufficiency for LH households in Gaza (about 8 percent) and Chiduku (about 4.4 percent). An analysis for SH households shows that across all survey sites, except in Chiduku (the FSSI decrease slightly with TGR), the level of food self-sufficiency is at 4 to 8 percent higher with TGR than under the status quo.

10.2 Implications for Policy and Development Planning

This thesis showed that distortions resulting from an externality in grazing resource utilization can be eliminated by a combination of redefining property rights and then establishing a market in grazing rights based on the redefined property rights. The establishment of TGR is likely to enhance the ability of the regulators of grazing resource use to manage the rangelands better. Given the support for TGR by about 43 percent of the households, there is thus potential for implementing TGR for grazing management. While the design and implementation of TGR needs to be tailored to specific regional circumstances, general guidelines that may be useful in initiating the implementing process are outlined.

10.2.1 Development of a legislative framework

Bearing in mind the very large number of households that will be affected by implementing the system of TGR, and that it may be difficult to reach a solution that is agreeable to most parties, first, it is important to build support for the passage of legislation establishing TGR. A draft TGR law can be established based on experience from implementing tradable pollution permits (Hahn, 1989; Oates, 1988) and tradable water rights (Rios and Quiroz, 1995; Rosegrant and Gazmuri, 1994). An intensive awareness campaign and debate in a few initial target areas (targeting areas in NR IV followed by areas in NRIII as these are likely to have the highest potential positive returns with tradable grazing rights) will help ensure that the final design and implementation of the legal framework is done in a transparent and participatory manner.

The process of establishing property rights involves enshrining legal ownership of the grazing right permits. The process should spell out the legal rights which allow effective recourse to the legal system if the physical rights are violated. The establishment of grazing rights will need to determine how grazing permits are defined and exchanged. The definition is important – it needs to be as simple as possible but all encompassing to allow for community implementation of the system of TGR. The question that has to be answered is whether grazing permits will be based on the number of cattle grazed, irrespective of their age, or on the basis of livestock units (LU). Technically, basing the grazing rights on the concept of LU makes more sense, but this may be problematic when used by the communities.

Legal enforcement mechanisms will be important in dealing with rights that may be violated. This will especially apply to ensuring that those households who are supposed to de-stock do so as and when required unless they become dynamically efficient. The established legal system will need to make an adequate provision of such public goods as the policing system so that the costs of enforcing the rights are low.

The design and implementation of the legislation should pay particular attention to the initial allocation of grazing rights, and the creation and maintenance of a grazing rights registry. In particular, care needs to be taken that the farmers are well-informed regarding the need to register their rights and the procedures for doing so. Public authorities will also need to design and enforce environmental laws. New institutions or administrative structures would be required to enforce rangeland quality. With experience from pollution control using tradablr permits – the administrative system to be designed needs to be as simple as possible to reduce transaction costs. Otherwise the implementation of TGR may be impossible.

At the heart of the legal approach referred to above, should be the development of a comprehensive analytical framework for grazing resources management. Grazing resources should be managed in the context of a communal grazing strategy that reflects the nation's social, economic, and environmental objectives and is based on an assessment of the communal area's grazing resources.

To ensure that farmers will identify with the new grazing policy, and that the policy conforms to reality on the ground, the policy makers will need to work closely with local authorities – the district councils and the chiefs. Preparing the draft versions of the law with a willingness to accommodate reaction will be critical to success. Farmers will have to be convinced that their concerns have been considered and dealt with adequately. Involving local communities will also avoid delays in implementing stemming from insufficient involvement of farmers in the design of the proposed law and opposition from the few that benefit from maintaining the status quo.

10.2.2 Institutional development for grazing resources management

For any property regime to function it has to be backed by effective administrative and policing systems that ensure compliance, fairness in grazing resource allocation and that can preside over and manage resource-based conflicts. If the authority system is weak, becomes rent seeking or breaks down, then resources cannot be managed sustainably and any property regime can degenerate into open access. With respect to the communal areas of Zimbabwe, generally, traditional leadership has been weakened by the political structure changes and cannot effectively manage the natural resources including the rangelands. Hence new institutional and administrative structures that can easily adapt to the rapidly changing political and economic environments are needed to manage common pool resources in the communal areas. Under this new system, there is need for clarification of who the responsible authority for land administration is.

To establish effective institutions to draft the regulations and to implement the law efficiently and fairly requires ensuring that the herders' or grazing associations and public institutions, such as the ministry of agriculture, and district councils are able to carry out their responsibilities. Sufficient budgetary resources need to be devoted for their effective functioning. It may be useful to contract for technical assistance to draft the regulations and to strengthen farmer herders' or grazing associations. In addition, it is important to ensure that staff of the public institutions is capable, that they fully understand and support the new legislation. Given the role of public institutions in the initial allocation grazing rights and in the subsequent operation of the grazing rights market, poorly trained or corrupt employees could prevent the market for grazing rights from ever developing or functioning effectively.

10.2.3 The need for collective action in grazing control at the community level

To receive the full benefits of grazing control, the decision cannot be made on an individual household basis; it has to be made at the level of the community, as the benefits of improved grazing can only be achieved if the stocking rates of the communal grazing lands are reduced. While individual households may move animals from one region to another, in order to avoid drought losses, change herding patterns in the face of declining feed resources, and shift to cutting and carrying of browse during droughts (Scoones, 1990; Campbell et al., 1993), there is little evidence that communities actively manage cattle numbers on a community-wide basis (Campbell, et al., 2000). There is therefore need to establish community grazing associations who will be responsible for the community-wide management of grazing resources. There are a few community-based grazing management organizations in South Africa, but these are the exception rather than the rule (McAllister, 1986; Cousins, 1996; Kepe and Scoones, 1999). Lesotho is one country in southern Africa which is making an effort to establish community-based grazing associations country-wide that are responsible for grazing management (MAFS, 2003). Lessons can therefore be drawn from South Africa and Lesotho on the development of these community grazing associations. At home, lessons in organizing communities to manage natural resources can also be drawn from the CAMPFIRE experiences. The only difference in management would be that whilst the wildlife resources managed under CAMPFIRE are communally owned, cattle that graze on communally held rangelands are owned by individual households.

10.2.4 Issues of the allocation of grazing rights

There are several issues related to the initial allocation of TGR. The key characteristics of formal secure tradable grazing rights is that the rights are independent of land and can be traded separately from land within a legal and institutional framework. The market for grazing rights can be set up by (1) grand-fathering, (2) holding an auction, (3) allocation of grazing rights proportional to current cattle holdings, and (4) the prior appropriation doctrine: only those who already have livestock prior to the implementation of TGR obtain primary rights to grazing resources. Successive claimants can only obtain rights that are contingent on those with prior rights having received their allocations (Rosegrant and Gazmuri, 1994).

A grand-fathering system discriminates against new entrants to the market, so it can be deemed unfair to new entrants. An auction system also has its drawbacks. The herders have to pay the auction price for their first allocation of permits, and this represents a financial burden on herders, particularly the poor, equal to the burden under a tax system, affecting their competitiveness. With the proportional allocation and prior rights systems, non-cattle owners would not directly benefit from grazing resource control using TGR which would be highly regressive. With the auction system, the revenue raised can be used to invest in grazing resources and meeting the administrative costs of implementing tradable grazing rights.

The actual allocation of grazing rights should be a two-step process: grazing rights should be first assigned to the grazing associations based on veld and zero grazing assessments and then assigned to the individuals/households by the associations according to guidelines issued by a Grazing Council (this would be a body that oversees the grazing associations). The titles to grazing are registered only at the individual/household level and not at the grazing association level. The two-step method has two advantages over direct assignment to individuals/households. First, it is easier for the grazing association rather than the Government to verify stock ownership and any innovation resulting in dynamic efficiency in grazing provision by individual farmers. Second, it leads to titling many users simultaneously. This block titling of grazing rights reduces unit titling costs and helps resolve conflicts.

Community representatives will need to be elected for the operation of grazing associations. It is important to ensure that elections for the officials of the grazing associations are conducted in a transparent and fair manner so that if members of the association are dissatisfied with the way it is run, they can remove the officials that are not performing satisfactorily. While this will not necessarily eliminate unjust allocations, it may help reduce them.

The communities, through the grazing associations and the grazing council will need to convene meetings to clarify on the following issues/questions pertaining to grazing rights allocation:

- Which grazing right allocation option to adopt? Communities could select amongst the following recommended options[27]:
    - The grazing rights are free only once, allocated equally to all relevant households/individuals of the community regardless of the number of cattle (if any) owned. Thereafter rights are traded and any new entrants will have to buy the rights,
    - The grazing rights are allocated equally for free every year, allowing for new entrants. In this case the long term security is forefeited.
    - Initially all rights are auctioned and then re-auctioned every five years, and
    - The grazing rights are initially allocated for free and then re-allocated for free every five years.
- Except for the system of auctions, it has to be decided who exactly gets allocated grazing rights. Is it the household (and how is it defined) or is it every adult individual?
- How often must the grazing rights be allocated? Is it every year or some other specified time periods?

[27] It should be noted that after the allocation, either by auction or for free, farmers then trade the rights within the community or with outsiders.

- How are grazing rights resulting from household/individual innovativeness going to be dealt with? For example, if someone decides to zero graze their cattle after being allocated grazing rights, are those rights permanently theirs or they are still going to be re-allocated during the next re-allocation of permits?

10.2.5 Long term security of rights

The lack of 1ong term secure access to grazing rights is likely to discourage investment in activities that enable access to more grazing rights as well as the support for the system of TGR. There is need to pass legislation to permit secure and well-defined tradable grazing rights. Secure grazing rights give farmers the confidence that, once they obtain the rights to grazing generated by their investment (e.g. practicing zero grazing due to purchase of feeds or fodder production), these rights will be theirs to keep or sell to other farmers within or outside their community. In this case TGR have to be allocated on a long-term basis. The advantages and disadvantages of short-term and long-term titling of grazing rights have to be weighed carefully. Annual allocations will enable tight tracking (Campbell, et al., 2000) of the community herd size over time:

i. if changes in household herd sizes occur during the year, they are readily reflected,
ii. new entrants are readily attended to, and
iii. if a household sells off cattle, the benefits of doing so are realized early enough.

10.2.6 TGR and the creditworthiness of smallholder farmers

If the system of TGR is soundly implemented, and access to grazing rights is long-term and not short-term, theoretically farmers would also benefit from having more secure grazing rights even if they do not own cattle. The grazing rights, if legally recognized, can be viewed as an asset that can be used as collateral for loans at the banks by small-holder farmers. Assuming that there are substantial grazing rights per household with a good price, the grazing rights would be particularly beneficial to the SH farmers who have few or no other sources of collateral. And because of their divisibility, grazing rights could also give the smallholder farmers the possibility of mortgaging only part of their grazing rights for loans in place of other assets.

10.2.7 Environmental groups and trade in grazing rights

In theory, the grazing right market could be open to groups other than just the members in a given community. This would give other interested parties, environmental groups, or indeed the government, the chance to enter the permit market. Environmental groups could buy permits and then not use them thus determining a given level of grazing pressure and hence rangeland quality. If the buy-out of grazing rights is big enough, it would increase the price of the grazing rights. The increase in price could in turn stimulate innovation for further environmental damage reductions, thus inducing dynamic efficiency in grazing resource use. Dynamic efficiency in grazing control could result from farmers practicing zero grazing. This could be achieved by producing fodder for the cattle or if farmers start supplementing their cattle feed requirements with feed concentrates. Thus, cattle are taken off the veld, resulting in an improvement in the quality of grazing resources.

An advantage of an open grazing right market is that it would give the regulatory body – be it the state or a local authority - the opportunity to intervene and buy permits if it decided that rangeland damage needs to be further reduced. This gives the system much greater flexibility in adjusting to changing policy goals. This flexibility cannot be over-emphasized in its importance in addressing long-term sustainable and equitable community growth.

A disadvantage of the open grazing right market is that a small number of "big" herders or even a monopolist may dominate the market. The monopolist may try to corner the market by hoarding permits and refusing to trade them, so creating a barrier to new herders entering the cattle industry. Thus, a grazing permit system can contribute to non-competitive behavior in the communal area cattle industry. To avoid this risk, the regulatory body can develop an appropriate regulatory framework that discourages an unnecessary hoarding of grazing rights, for example a tax on the grazing rights that are not given-up for trade in any given year or time period.

10.2.8 Polluter pays principle and trade in grazing rights

One complaint against the system of tradable permits is that they would give herders the right to damage the environment to the extent dictated by the number of permits initially issued. This is contrary to the Polluter Pays Principle, and the wrong signals are being sent to the herders. However, marketable permits are not the only instrument with this property: standards are also in effect saying that a certain level of environmental damage is acceptable and give herders the right to damage the pastures up to that level. The main difference between TGR and other alternative grazing policies, therefore, is not the property rights allocation of TGR but the tradability of the grazing rights.

10.2.9 Monitoring and enforcement

However, grazing rights markets are not a panacea. Grazing management involves high transaction costs, which also reduces an efficient allocation of grazing resources over time. The transaction costs involve information costs, enforcement or policing costs and contractual costs. Contractual costs are incurred when legislative efforts are directed to promote collective forms of organization and giving herders grazing permits. Enforcement costs will involve monitoring costs and costs of imposing penalties, or other legal costs. Information and enforcement costs are relevant to any of the grazing management systems – standards, taxes and tradable permits. However, these costs would probably be considerably higher with standards or taxes since there would be no incentive to regulate neighbors.

Since the proposed system of TGR involves some degree of control on grazing pressure through possible de-stocking, there is need for rigorous monitoring and enforcement since cheating by continuing to graze supposedly de-stocked cattle might be highly profitable as other households reduce on their cattle numbers. The ideal and cost-effective system would be for the range users or local communities themselves to be responsible for the monitoring enforcement if they are able to perceive rangeland management regulations to be in their long-term interest. However, individuals will tend to weigh personal costs versus the personal benefits they get.

If rewarding innovations under the system of TGR is going to be acceptable, then monitoring and enforcement of grazing resource use is going to be complicated. Assessment would need to be done of the veld carrying capacity, crop residues availability and the number of cattle supported under a zero grazing system. Tight monitoring would be required to ensure that livestock supposedly being reared under zero grazing management are not put on the veld.

10.3 Areas of Further Research

A wide gap exists between feelings that "something ought to be done" and the design and implementation of effective economically productive countermeasures. Resource and environmental systems are immeasurably complex, involving physical, biological, social, economic and political components. Uncertainty and unpredictability are the rule and not the exception. Failure to account for the interaction of all components may lead to inappropriate, expensive and unsuccessful attempts to achieve sustainable grazing resource utilization. Thus, detailed experimental analyses are required to obtain with some accuracy the revealed preferences of farmers with respect to the potential of using TGR for grazing management. One way of doing this would be to do a comparison of household preference of alternative policies at different points in time, allowing an examination of the power of the model to forecast future support for grazing policies. A panel study would be useful in examining the persistence of an individual household's preference under different economic environments.

The critical variable in the assessment of the economic advantages of TGR over the status quo is the grazing pressure or carrying capacity. There is a debate in the literature on how the carrying capacity is determined especially with reference to the communal area situation where livestock are kept as capital assets and whose weight-gain productivity for purposes of increased off-take is less important. Using total herbaceous forage productivity as the single criterion to predict the livestock support capacity has been criticized because biomass quality and feeding value for livestock are largely ignored. Calculations of livestock sustainability based on tones to dry matter produced per hectare ignore the variable quality of forage as animal feed. Both the precision and the utility of evaluating feed supply-demand are however open to doubt because of several factors:

- Little is known about the carryover effects of grazing between years,
- Rainfall based estimates of biomass production rarely take into account landscape heterogeneity and variability in productivity,
- Compensatory re-growth of grazed and browsed plants, resulting in higher quality and, occasionally, in higher production, is frequently ignored.
- Carrying capacity should be linked to nutritive value, in particular to the crude protein (CP), energy and mineral content of the total dry matter.

There is therefore need to develop and agree on the appropriate methods for estimating the potential and present carrying capacities of the rangelands given the varied vegetation species with different forage characteristics and the cattle feed requirements. These values are key in the process of policy formulation for grazing resource management.

Because data on the relationship between grazing pressure and crop and livestock productivity are not available, primary research must be encouraged. The research should clearly show the links between rangeland productivity and cattle productivity parameters like mortality rates, calving rates, calving intervals, draft power and milk output; and links between rangeland productivity and crop productivity. The generation of such information would enable the estimation of damage and costs function that would allow reaching concrete conclusions on the feasibility and viability of implementing TGR as a policy for grazing control in the communal areas.

The results of this thesis are based on a scenario where grazing rights are initially allocated for free and then re-allocated for free every five years. Further research is required to assess the likely impacts of the alternative allocation scenarios, i.e.:

- The grazing rights are free only once, and thereafter rights are traded and any new entrants will have to buy the rights,
- The grazing rights are allocated equally for free every year, allowing for new entrants, and

- Initially all rights are auctioned and then re-auctioned everyfive years.

There is no point in introducing a new environmental policy if it is not easy to enforce. Enforcement costs must be taken into account in any overall assessment of environmental policies. High enforcement costs increase the optimal grazing level and reduce environmental quality. Grazing management involves high transaction costs, which also reduces an efficient allocation of grazing resources over time. Transaction costs involve information costs, enforcement or policing costs and contractual costs. The risk of under-estimating these costs are high. Research is needed on the enforcement requirements of TGR and other grazing management options. Hence, there is need to quantify these different costs components as accurately as possible so as to ultimately determine the cost effectiveness and distributional impact of TGR.

The analysis on the likely impact of TGR presented in this thesis has been partially dynamic in nature. Whilst the partially dynamic analyses are important as a first step to showing the important considerations in the design of policy measures for grazing resource control, fully dynamic analyses are required to test the viability of implementing TGR. The analyses should attempt to include all major crops and livestock in the model, unlike this thesis which simply includes only maize and cattle in the model.

The analysis presented in this thesis focused on intra-community trade in grazing rights, but there is potential for establishing inter-community trade in grazing rights. Taking the case of Nerutanga with currently low grazing pressure, surrounding communities who could be overgrazing could buy grazing rights/permits from Nerutanga. Conversely, the Nerutanga community could approach other communities and sell their "excess" grazing rights. An extension to inter-community trade would result in higher returns when compared to the intra-community trade scenario. This is because households who would not have secured grazing rights within own communities would secure them from other communities and hence avoid unnecessary de-stocking. Allowing for inter-community trade will be very important during drought periods when trade could be established even between distant places. The feasibility of such distant trade would depend on how far households are willing and able to pay for the costs of moving their cattle versus the perceived benefits from such a movement.

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ANNEX 1: QUESTIONNAIRES

Annex 1.1: Household Information and General Attitudes Towards Grazing Resource management

HOUSEHOLD SURVEY **QUESTIONNAIRE** 1
DEPARTMENT OF AGRICULTURE ECONOMICS AND EXTENSION
UNIVERSITY OF ZIMBABWE, 1999

Date ....
Household number ....
Household name ....
Village ....
Enumerator's name ....
Start time of interview ....
End time of interview ....
Total time taken .... Hours .... Minutes

SECTION A: Household Characteristics

A1. Sex of household head 1. male 2. Female: a). De facto b). widow

A1.1. Age of household head: ..... years **or** year born: 19....

A1.2. Education level of household head:
1. Did not attend school
2. Primary education
3. Secondary education
4. Tertiary education

A1.3. Employment status of household head:
1. Farmer
2. Non-farm employment (local)
3. Commercial farms
4. Non-farm employment (not local)
5. Other (specify):

A2. Household size (excluding household head): ....

A3. Fill the table for all household members who are here for six months or more of the year and who eat from the same kitchen (except for household head)

no.	Name	Sex	Age (years)
1.		M….. F…….	
2.		M….. F…….	
3.		M….. F…….	

SECTION B: Land holding

B1. Number of household fields: ....

B2. If you were to plant maize in each of your fields, how many 10 kg maize seed bags do you think you would use? Indicate whether field was fallow or not during the 1995/96 cropping season and the year you acquired or opened up the field.

Field number	Number of 10 kg maize seed bags	Fallow? 0. No 1. Whole field 2. Partly	Number of 10 kg maize seed bags for fallow area	Year opened up or acquired
1.				
2.				
3.				

B2.1 If you have some of your land fallow, what are the reasons?

1. Lack of labour to cultivate all the land
2. Lack of draft power to cultivate all the land
3. The land is more than that required to meet household food needs
4. Other (specify): ....

SECTION C: LIVESTOCK PRODUCTION

C1. Which livestock does your household own?

Livestock type	# owned now	# of owners now	# Oxen (> 4 yrs castrated)	Bulls (> 4 yrs uncastrated)	# Cows in calf	# cows not in calf	# steers (1-4 yrs)	Heifers (1-4 yrs)	Calves (< 1 yr)
CATTLE									
GOATS			XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXX	XXX
SHEEP			XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXX	XXX
DONKEYS		XXXX	XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXX	XXX
PIGS		XXXX	XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXX	XXX
POULTRY		XXXX	XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXX	XXX
RABBITS		XXXX	XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXX	XXX

C2. What were your cattle births, deaths, sales, slaughters and purchases since 1990?

YEAR	Number of cattle	Number of calves born	Number of calves died	Number of adult cattle died	Number of cattle slaughtered	Number of cattle sold	Number of cattle purchased
1998							
1997							
1996							
1995							
1994							
1993							
1992							
1991							
1990							

C3. Are you milking your cows ? 0.No 1. Yes

C3.1 If yes to C3 above, how many cows are you milking now: .....

C3.2 For each of the cows you are milking, give details in the table below.

Cow number	number of months since calving	Milk output per day (liters)
1.		
2.		
3.		

C3.3 If you are milking your cows, do you sell the milk? 0. No 1. Yes

C3.4 If you sold milk as from October 1995 up to January, 1997, please give details in the table below.

Period of milk sales	Number of cows milking	Estimated total income ($)
Oct.95 - Apr.96		
May96 - Sept.96		
Oct.96 - Jan.97		

C4. Did you buy any cattle feeds since October 1995? 0.No 1.Yes

C4.1 If yes, fill in the following table concerning cattle feed purchases since October, 1995.

Feed type	Quantity purchased	Total expenditure (incl. transport costs)
1.	....	....
2.	....	....
3.	....	....
4.	....	....
5.	....	....

SECTION D: RANKING ACTIVITES

D1. Rank the following activities according to their contribution to household income. Do not rank inapplicable activities.

Activity	**Rank**
Crops	....
Remittances	....
Cattle	....
Hired labour (local)	....
Small ruminants	....
Vegetable production	....
Poultry and Rabbits	....
Timber forest products (poles, firewood, wood carvings etc.)	....
Non-timber forest products (madora, mice, wild life, mushrooms etc.)	....
Other (specify)	....

SECTION E: FARMERS' GENERAL ATTITUDES AND BEHAVIOR

E1. Is any one of your household a member of a farmer organization?

0. No 1. Yes

E2. Do you have access to credit for:

Activity	Access to credit	If yes, what are the two most important sources of credit
Crop production	Y / N	
Cattle production	Y / N	
Other livestock production	Y / N	

E3. Do you attend agricultural extension meetings? 0.No 1.Yes

E4. If yes, when was the last time you attended a meeting with your extension agent? Year:..... Month:...............

E5. Is your cattle herd adequate for the needs specified below? For non-cattle owners, this translates to how many animals you would need to meet the needs specified below.

Need	Number of cattle adequate?	Number available for need	If no, additional number needed
1. Overall	**0. No 1. Yes**		
2. Draft power	0. No 1. Yes		
3. Manure	0. No 1. Yes		
4. Income	0. No 1. Yes		
5. Social/cultural	0. No 1. Yes		

E6. Given the number of cattle you have now and that the average price of cattle in this area is $1 800 - **regardless of whether you are buying or selling cattle** and that you need cattle for manure and draft power, among other things - how many cattle would you be willing to sell per year if the price was:

Price	Z$500	Z$1000	Z$1500	Z$2500	Z$3500	Z$5 400
# of cattle you would sell						

E7. Which is more important to you, grazing land or arable land?

(1). arable land more important

(2). grazing land more important

(3). both are equally important

E8. The government is concerned about the problem of overgrazing in the communal areas. Overgrazing is resulting in river and dam siltation, important medicinal plants are being lost as well as thatching grass, among other things. As a result the government has thought of adopting a strategy to reduce overgrazing by making people pay for grazing. Payment will be per animal per year. Only those farmers who pay up will be allowed to graze their animals. Those who do not pay will not be allowed to graze their cattle. The money raised will be used to improve the veld by growing fodder legumes to improve on the condition of the veld.

(a).Would you be willing to Pay $ 600, 300, 150, 75, 50 per animal per year to graze your cattle on the communal grazing land?

0. No (go to b) 1. Yes (go to b)

(b).What is the maximum amount of money per animal per year, you would be willing to pay to graze your cattle on communal

grazing land, otherwise you would not be allowed to graze? $ ....

SECTION F: COMMITMENT TO PRESERVING GRAZING AND TIME PREFERENCE IN GRAZING ALLOCATION

F1. Over the past year, did you attend any meeting that among other things focused on conservation of the following natural resources: 1. grazing? 0. No 1. Yes

2. soil?	0. No	1. Yes
3. woodlands?	0. No	1. Yes

F1.1 If yes, how many such meetings did you attend? ....

F1.2 If no what were your reasons for not attending such meetings?

....

F2. If some time in the near future, meetings were organized to discuss on the conservation of the following natural resources, would you attend:

1. grazing?	0. No	1. Yes
2. soil?	0. No	1. Yes
3. woodlands?	0. No	1. Yes

F2.1 If you would not attend, why not? ....……

F3. Which of the following would you prefer?

1. Graze as much as possible today

2. Conserve grazing today, to have more grazing in the future

3. There is no difference 4. I don't know

F3.1 What are the reasons for your preference? ....

F4. If laws were to be set on the conservation of natural resources (pastures, trees, soils and rivers) whose would you respect more?

1. Government 2. District council 3. Local community

F4.1 What are your reasons to your answer in F4 above? ....

THANK YOU FOR ANSWERING OUR QUESTIONS

Annex 1.2: Crop Production and Utilization of Common Property Resources

HOUSEHOLD SURVEY **QUESTIONNAIRE 2**
DEPARTMENT OF AGRICULTURE ECONOMICS AND EXTENSION
UNIVERSITY OF ZIMBABWE, 1999

Date ....
Household number ....
Household name ....
Village ....
Enumerator's name ....
Start time of interview ....
End time of interview ....
Total time taken .... Hours .... Minutes

1. MARKETED CROPS

What crops did your household produce and market for the 1990 – 1998 seasons?

Crop		1998	1997	1996	1995	1994	1993	1990-1992
1.	Area (acres)							
	Output (50kg bags)							
	Sales (50kg bags)							
	Sales income (Z$)							
2.	Area (acres)							
	Output (50kg bags)							
	Sales (50kg bags)							
	Sales income (Z$)							

2. NON-MARKETED CROPS

What crops did your household produce but did not market?

crop		1998	1997	1996	1995	1994	1993	1990 - 1992
1.	Area (acres)							
	Output (50 kg bags)							
2.	Area (acres)							
	Output (50 kg bags)							
3.	Area (acres)							
	Output (50 kg bags)							

3. NON-AGRICULTURAL INCOME (SALES IN Z$)

How much money did your household get from selling the following forest and non-agricultural for the years listed below?

Income Source		1998	1997	1996	1995	1994	1993	1992	1991	1990
Forest: Timber Products	firewood									
	fiber									
	poles									
	wood carvings									
	other 1 …….									
	other2……..									
Forest: Non-Timber Products	mushrooms									
	small animals/birds									
	insects									
	honey									
	wild fruits									
	thatching grass									
	leaf litter									
	other1 ……..									
	other2 ………									
	handicrafts									
	brick making									
	blacksmithing/ tin-smithing									
	labor hiring out									
	stone carvings									
	gardening									
	cattle sales									
	small ruminants									
	poultry									
	other livestock									
	formal employment (local)									
	remittances/ employment outside									

4. USE AND AVAILABILITY OF COMMOM PROPERTY RESOURCES

Which of the following do you collect/use from the communal natural resources? For each of the products collected, what is the availability to day compared to 1, 5, 10, 20 and 30 years ago?

	COLLECT / USE?	**AVAILABILITY .... YEARS AGO COMPARED TO TODAY** **1. MUCH LESS 2. LESS 3. MORE** **4. MUCH MORE 5. DONT KNOW**				
Resource	Y / N	1	5	10	20	30
Firewood	Y / N					
Fiber	Y / N					
Poles	Y / N					
Wood for carvings	Y / N					
Mushrooms	Y / N					
Fish	Y / N					
Small animals/birds	Y / N					
Insects	Y / N					
Honey	Y / N					
wild fruits	Y / N					
thatching grass	Y / N					
leaf litter	Y / N					
Cow dung from veld	Y / N					
Stone carvings	Y / N					
Brick making	Y / N					
Fodder	Y / N					

5. INCOME DERIVED FROM THE USE OF COMMON PROPERTY RESOURCES

For each of the products collected from the communal natural resources, give an estimate in cash or in-kind per year of the value of the products you used. That is, if you were to buy these products how much money would you use per year?

Resource	**INCOME CONTRIBUTION (Z$)**		
Resource	1996-1998	1991 - 1995	1985 - 1990
firewood			
Fiber			
Poles			
Wood for carvings			
mushrooms			
Fish			
Small animals/birds			
insects			
honey			
wild fruits			
thatching grass			
leaf litter			
Cow dung from veld			
Stone carvings			
Brick making			
fodder			

THANK YOU FOR ANSWERING OUR QUESTIONS

Annex 1.3: Household Preference of Alternative Grazing Management Options

HOUSEHOLD SURVEY **QUESTIONNAIRE 3**
DEPARTMENT OF AGRICULTURE ECONOMICS AND EXTENSION
UNIVERSITY OF ZIMBABWE, 1999

Date	....
Household number	....
Household name	....
Village	....
Enumerator's name	....
Start time of interview	....
End time of interview	....
Total time taken	.... Hours .... Minutes

FARMERS' PERCEPTIONS ON THE OPTIONS FOR MANAGING GRAZING

There are several possible ways of making households not to overgraze that have been suggested. These possible ways of ensuring that grazing is conserved have been discussed at group meetings that were held in this area some three weeks ago. Whilst the answers obtained were for a group of people, today we want to know the opinions of your household to these ways that can be used to conserve grazing. Your answers to these questions are confidential and will not necessarily influence government policy formulation. Note that in each of the following questions none of the suggested pasture management options will be implemented by the government. We just want to know how you respond, therefore we ask you to feel free to answer all the questions.

1. TRADABLE GRAZING RIGHTS

Grazing is equally divided among owners and non-owners of cattle through an allocation of grazing rights. The number of animals required to graze each year will be determined on a yearly basis to reflect on grazing availability which depends on the amount of rainfall received. In this community a household can get a right graze a maximum of **4** cattle per year. Households with less than 4 cattle to graze can "sell" their extra shares (or all their shares in the case of non-cattle owners) to those households with more than 4 cattle. To ensure that there will be no cheating on the part of cattle owners, the current cards indicating the number of cattle a household has will be used. After selling or buying a grazing share, Agritex and Veterinary workers will ensure that updates are made to the permits. All households with excess grazing shares would be expected to have sold all their shares by a certain stipulated date. Failure to do so would result in all grazing shares being taken by the government. This will be done to avoid a situation whereby non-cattle owners or those with few animals withhold selling their excess shares so that cattle owners will be forced to cull more than the required number of cattle. On the other hand, to ensure that the rich farmers do not buy all the grazing shares to sell them later, no household will be allowed to buy any shares to sell them later. All transactions concerning grazing shares would be held at the local veterinary offices. No transactions will be allowed between farmers in the absence of veterinary officers. Those cattle owners with excess cattle who can not secure grazing for their cattle for that particular year will have to sell their excess cattle. The government will put into place a mechanism for ensuring that additional above the required number are destocked, unless a household can prove that they can supplement their cattle without using the natural rangelands. Of course the farmer will get some money each time they have to destock through selling their cattle. The community households themselves will be responsible for ensuring that no individuals within households get grazing shares. Government will not take into account issues specific to households e.g. that households have to have mombe yehumai, bhuru remusha, and the number of sons in a household.

A. (ask all households)
If this grazing management option were implemented, would you favour it? 0. No
1.Yes

A1.1 What are your reasons for your answer in **A1**?
....

....
....

A2. (ask cattle owners with more than 4 cattle only)

As a cattle owner with more than 4 cattle for your additional .... cattle are you willing to pay the following total amounts to obtain grazing for your cattle?

Amount per animal per year	WTP this total amount per year	Response	Instructions
a). $160		1. Yes 0. N0	If yes, go to **c** If no, go to **b**
b). $40		1. Yes 0. N0	If yes, go to **d** If no, go to **d**
c). $280		1. Yes 0. N0	If yes, go to d If no, go to **d**

d).What is the maximum amount you are willing to pay for all your cattle in excess of seven animals to obtain grazing for them? $ ....

e).As a cattle owner with more than seven cattle and were required to buy grazing from those with fewer animals or from non-cattle owners, what mode of payment would you prefer for the grazing rights?

1. Money 2. Plowing 3. Other (specify)...............................

A2.1 (ask cattle owners with more than 4 cattle)

In the following question we would like to know how many additional cattle (above 4) you would keep at the specified grazing rights prices.

Amount per animal per year	Total amount to be paid per year	Would still keep .... cattle?	If no, how many additional cattle above 4 would you keep
a). $40		1. Yes 0. N0	
b). $160		1. Yes 0. N0	
c). $280		1. Yes 0. N0	

A3.1 (ask non-cattle owners or cattle owners with less than 4 cattle)

As a non-cattle owner or a cattle owner with less than 4 cattle, are you willing to accept the following total amounts for your grazing shares so that those with more than 4 cattle can get grazing for their cattle?

Amount per animal per year	WTA this total amount per year	Response	Instructions
a). $160		1. Yes 0. N0	If yes, go to b If no, go to **c**
b). $40		1. Yes 0. N0	If yes, go to **d** If no, go to **d**
c). $280		1. Yes 0. N0	If yes, go to **d** If no, go to **d**

d).What is the minimum amount that you are willing to accept for your ....

grazing rights? Z$ ....

e).As a non-cattle owner or a cattle owner with less than 4 cattle, how would you prefer to be paid for selling your grazing rights?

1. Money 2. Plowing 3. Other (specify) ....

A3.2 (ask non-cattle owners or cattle owners with less than 4 cattle)
Would you still want to own more than 4 cattle, after it has been declared that farmers have to pay for grazing rights for all cattle above seven?   1. Yes   0. No

B. INDIVIDUAL OWNERSHIP OF GRAZING (ask all households)
Each household - with or without cattle - is given 14 acres of grazing land near the homestead or near their fields and they are responsible for managing that piece of land. Each household is expected to fence off their piece of grazing, otherwise other households would utilize their share of grazing land. With this option households no longer have to graze their animals outside the allocated portion. With this management option, no costs are paid for grazing. Households with more than 4 cattle will have their portions of grazing overgrazed and hence poor cattle performance or they will have to produce extra feed to ensure adequate feed for their cattle. Those with 4 or less cattle will have enough feed for their cattle for a whole year. Non-cattle owners will keep their portion of grazing until that time they have own cattle. People can not sell their grazing, but are free to rent out their grazing at an amount negotiated with the renter. **NOTE: THE HOUSEHOLDS WILL NOT BE ALLOWED TO CONVERT THE LAND INTO ARABLE LAND. HOUSEHOLDS DOING SO WILL BE FINED HEAVILY - UP TO Z$5 000.**

B1. If this grazing management option were implemented, would you favour it?
0. No   1. Yes

B1.1 What are your reasons for 1 above?
....
....
....

C. FORMATION OF GRAZING SCHEMES (ask all households)
In this option the community fences off its grazing area. Conflicts with neighboring communities are most likely to occur due to disagreements over the boundaries. Due to decreases in donor and government funding, households in the community will be expected to pay for half of the following costs: all the fencing costs (including labour), fence maintenance costs, and cost for sinking two to three boreholes for watering cattle in the paddocks. Households will be required to meet the full costs of guarding the grazing fences and the provision of money to source seed for grasses and legumes to improve grazing. Cattle owners will be required to contribute more than non-cattle owners per year. Farmers will be required to do grazing rotations **(explain concept of grazing rotations)**. In this option there is no equal sharing of resources between owners and non-owners of cattle as has been suggested for tradable and individual grazing rights.

C1. (ask all households)

If this grazing management option were implemented, would you favour it?

0. No 1. Yes

C1.1 What are your reasons to 1 above? ....
....

D. TAXING CATTLE OWNERS (ask cattle owners only)

This form of managing grazing is based on the principal that households will be required to pay tax per cattle owned. Money raised through this tax system will be used for local community development projects e.g. dams, schools, clinics etc. A mechanism will be put in place to make sure that the money raised is properly used for the benefit of the community.

D1. If this grazing management option were implemented, would you favour it?

0. No 1. Yes

D1.1 What are your reasons to 1 above? ....
....

D1.2. (Ask cattle owners only)

In the following question we would like to know how many cattle you would keep at the specified grazing taxes.

Amount per animal per year	Total amount to be paid per year	Would still keep .... cattle?	If no, how many cattle would you keep?
a). $10		1. Yes 0. N0	
b). $20		1. Yes 0. N0	
c). $40		1. Yes 0. N0	
d). $80		1. Yes 0. N0	
e). $100		1. Yes 0. N0	

f). If yes to (e) above, at what tax level would you consider reducing the number of cattle you own? $ .... per animal per year?

D1.3. (Ask those without cattle only)

Do you think the system of paying taxes will make you to still want to own cattle?

1. Yes 0. No

D2. (ask all households)

On the other hand, the tax system can be structured in the following way: households with 4 or less cattle will not be required to pay any tax. However, households with more than 4 cattle will be required to pay tax for additional cattle above 4.

D2.1. If this grazing management option were implemented, would you favour it?
0. No 1. Yes

D2.2 What are your reasons to 1 above?
....
....

D3. (ask cattle owners with more than 4 cattle only)

As a cattle owner with more than 4 cattle, for your additional .... cattle, are you willing to pay the following total amounts in taxes for your cattle?

Amount per animal per year	WTP this total amount per year	Response	Instructions
a). $80		1. Yes 0. N0	If yes, go to **c** If no, go to **b**
b). $20		1. Yes 0. N0	If yes, go to **d** If no, go to **d**
c). $160		1. Yes 0. N0	If yes, go to **d** If no, go to **d**

d).What is the maximum amount you are willing to pay in taxes per year for all your cattle in excess of 7 animals? $ ....

D3.1 (ask cattle owners with more than 7 cattle)

In the following question we would like to know how many additional cattle you would keep at the specified grazing taxes.

Amount per animal per year	Total amount to be paid per year	Would still keep .... cattle?	If no, how many additional cattle above 7 would you keep?
a). $40		1. Yes 0. N0	
b). $80		1. Yes 0. N0	
c). $100		1. Yes 0. N0	
d). $120		1. Yes 0. N0	

e). $160		1. Yes 0. N0	

f). If yes to (e) above, at what tax level would you consider maintaining a herd size of seven or less cattle? $ .... per animal per year?

D4. (ask households without and households with less than 7 cattle only)
Do you think the system of taxing those with more than 7 cattle will make you to still want to own more than 7 cattle? 1. Yes 0. No

E. FORMATION OF COMMUNITY GRAZING MANAGEMENT

With this option, the community have meetings to decide on its management system: boundaries of its grazing, who should be allowed to graze, the maximum number of cattle that will be kept per household and improvement of the veld by planting fodder grasses and legumes. All members in that community can graze in the pastures meant for that community but all members outside the community are not allowed. Households may contribute to veld improvements in labour and in cash as agreed by the community. Violators of the community by-laws will be sanctioned according to laid out specifications. It should be noted that with this system of grazing management there will be no intervention from outside even from the government, all the necessary grazing management will be done by the community. If the community will observe its laid down by-laws, the conservation of grazing grass will be successful and if management is poor, conservation of pastures will not be successful.

E1. (ask all households)
If this grazing management option were implemented, would you favour it?
0. No 1. Yes

E1.1 What are your reasons to 1 above? ....
....

F. PRODUCTION OF FODDER ON INDIVIDUAL PLOTS

In this option farmers continue using the veld in what ever way they are currently using it. With time, the veld will deteriorate to the extent that households will have to produce fodder to supplement their cattle feed. Fodder production will be on farmers' own arable plots or along contour ridges.

F1. If this grazing management option were implemented, would you favour it?
0. No 1. Yes

F1.1 What are your reasons to 1 above?

....

F2. (ask all cattle owners only)
As a cattle owner with .... cattle, are you willing to pay the following total amounts in fodder production to have enough feed for your cattle?

Amount per animal per year	WTP this total amount per year	Response	Instructions
a). $180		1. Yes 0. N0	If yes, go to **c** If no, go to **b**
b). $60		1. Yes 0. N0	If yes, go to **d** If no, go to **d**
c). $240		1. Yes 0. N0	If yes, go to **d** If no, go to **d**

d).What is the maximum amount you are willing to pay per year to produce fodder for all your cattle? $ ....

F2.1 (ask cattle owners only)
In the following question we would like to know how many cattle you would keep at the specified fodder production costs.

Amount per animal per year	Total amount to be paid per year	Would still keep .... cattle?	If no, how many cattle would you keep?
a). $180		1. Yes 0. N0	
b). $60		1. Yes 0. N0	
c). $240		1. Yes 0. N0	

F3. (ask households without cattle only)
Do you think the system of producing fodder at $60, $80, $100, $120 and above $120 per year per animal will make you still want to own cattle?

$60	1. Yes	0. No
$80	1. Yes	0. No
$100	1. Yes	0. No
$120	1. Yes	0. No
above $120	1. Yes	0. No

G. NO ACTION OPTION (Status Quo)

Farmers continue with the present practice of grazing: non-owners do not have a share in grazing, people continue grazing as many animals as they want, farmers continue to settle in grazing areas, farmers continue to expand area under cultivation and hence reducing area for grazing.

G1. (ask all households)

If this grazing management option were implemented, would you favour it?

0. No 1. Yes

G1.1 What are your reasons to 1 above?

....

H. Of the seven grazing management options presented above, which three would you prefer? How would you rank these three options, starting with the most preferred?

Option	Preferred *(tick)*	Rank
1. Tradable Grazing Rights		
2. Individual ownership of grazing		
3. Formation of grazing schemes		
4a.Taxing farmers, irrespective of cattle owned		
4b.Taxing farmers with more than 10 cattle		
5. Community grazing management		
6. Fodder production		
7. Continue with present practice		

THANK YOU FOR ANSWERING OUR QUESTIONS

Annex 1.4: Rules of Grazing Resource Utilization

HOUSEHOLD SURVEY QUESTIONNAIRE 4
DEPARTMENT OF AGRICULTURE ECONOMICS AND EXTENSION
UNIVERSITY OF ZIMBABWE, 1999

Date ....
Household number ....
Household name ....
Village ....
Enumerator's name ....
Start time of interview ....
End time of interview ....
Total time taken .... Hours .... Minutes

SECTION A: UTILIZTION OF GRAZING RESOURCES

1. Does your household have a private plot to graze cattle? 1. Yes 0. No

2. Are there any rules on specific locations from where this community can graze its livestock? 0. no 1. yes, what rules?

....

2.1 If yes, do you willingly follow these rules on where to graze your livestock? 0. no 1. yes

2.2 From you own perception, do other households follow the rules of where to graze their livestock? 0. no 1. yes

2.3 Can you graze your livestock from communities outside your community without facing charges? 0. no 1. yes

2.4 If no, what is / are the penalty (ies) for grazing your cattle outside your community grazing boundaries?
....

2.5 Do you know of anyone who has been punished for grazing their cattle outside your community grazing boundaries? 0. no 1. yes

2.6 If yes, who made the rules about the number of cattle a household can keep? (combinations are acceptable)

1. Government
2. district council
3. chief
4. village head
5. local community

3. Are there any rules on the number of cattle your household can graze on the community grazing lands? 0. no 1. yes, what rules?

....

3.1 If yes, do you willingly follow these rules on the number of cattle you graze on the community grazing lands? 0. no 1. yes

3.2 From your own perception, do other households follow the rules on the number of cattle that they have to graze on the community grazing lands? 0. no 1. yes

3.3 If yes, what is / are the penalty (ies) of not following the rules on the number of cattle your household can graze on the community grazing lands?

....

3.4 If yes, do you know of anyone who has been punished for not following the rule(s) on the number of cattle your household can graze on the community grazing lands? 0. no 1. yes

3.5 If yes, who made the rules about the number of cattle a household can keep? (combinations are acceptable)

1. Government
2. district council
3. chief
4. village head
5. local community

4. Do you think there is enough grazing in this community for all the livestock of this community? 0. no 1. yes

4.1 Do you think there is enough grazing in this community to meet the livestock feed requirements for your household? 0. no 1. yes

4.2 How can you describe the degree of overstocking in this community?

1. serious
2. moderate
3. not at all
4. don't know

4.3 (If the answer to 4.2 is 1 or 2): In your opinion why is it that there is overstocking?

1. government encourage farmers to keep more cattle
2. people do not sell their cattle because of multiple ownership in the household
3. households from other communities graze on this community's grazing lands
4. less land for grazing because of expansion in area under cultivation
5. less land for grazing because of an increase in community population which result in

an increase in the area under settlement
6. Others: **specify** ....

5. It is proposed that a committee can be set up to control the number of cattle that can be kept on the grazing lands of this community. It is expected that this committee will closely monitor the number of cattle kept and will punish those who do not follow the rules by making them pay fines or ban them from using community grazing lands. If such a committee were set up, would you favour it? 0. no 1. yes

5.1 If such a committee were set up and composed of individuals from within this community, the district council or the government, would you favour it? Rank the alternative organizations giving 1 to the most preferred option.

ORGANISATION	**FAVOUR IT?**		**RANK**
Local	0. no	1. yes	....
District council	0. no	1. yes	....
Government	0. no	1. yes	....

6. If this community were required to reduce the number of cattle that can be grazed on the community grazing lands and it was proposed that households within this community monitor each other on the number of cattle they keep, would you be willing:
(i) to monitor other households? 1. yes 0. no, why not?
....

(ii) to be monitored by other households? 1. yes 0. no, why not?
....

6.1 If your household were required to reduce the number of cattle it grazes on the community grazing lands with households not complying being fined:
(i)would you comply? 0. no 1. yes
(ii)do you think other households would comply? 0. no 1. yes

7. How do you compare the distance traveled to get good grazing for your cattle today when compared to:

1 year ago ....
5 years ago ....
10 years ago ....

CODES: 1. much more 2. more 3. less 4. much less 5. same 6. don't know

8. Do you ever graze your animals in grazing areas that are designated as grazing areas for other communities other than yours ? 0. no 1. yes 2. Grazing is for all

8.1 If yes, how often do you graze outside your boundaries.
....

8.2 If no, why don't farmers go and graze their animals in grazing areas that belong to other communities?

1. Distance is prohibiting
2. There is no difference in amount of grazing than is available locally
3. People are fined for using other community's grazing
4. Other (specify): ....

9. Do you agree that cattle owners are benefiting more from the use of grazing resources than non cattle owners? 0. no 1. yes

9.1 If no, why not? ....

9.2 How do non-cattle owners benefit from the use of grazing lands?
....

10. When you sell cattle what is it that really make you want to sell your cattle?
1. high prices 2. cash needs 3. other specify ....

11. What do you think an increase in crop yields and crop prices will do to your willingness to sell cattle?
1. I would sell more cattle 2. I would sell less cattle 3. I don't know

12. Do you think an increase in crop prices would make your household increase the area under crops ? 0. no 1. yes

13. Supposing you do not have cattle, if it happens that you acquire cattle today do you have to approach any one and inform them that you have acquired cattle? 0. no 1. yes

13.1 If yes, who do you have to approach? ....

13.2 If yes, would those you inform prevent you from grazing your cattle on the community grazing lands? 0. no 1. yes

14. Do you grow fodder in your fields? 0. no 1. yes

14.1 Do you grow fodder along contours? 0. no 1. yes

15. Does your household contribute anything to improving the condition of your grazing lands? 0. no 1. yes

16. If yes, what contributions does your household make to improve the condition of your grazing lands? ....

17. If households in this community were required to contribute towards the improvement of grazing lands - in any of the ways listed below - what would your household do? Which mode of contribution would your household prefer? Rank 1 - 3, 1 being the most preferred.

	WHAT HOUSEHOLD WOULD DO	RANK PREFERENCE
(i). cash contributions:	....	....
(ii). reduce the number of cattle grazed:	....	....
(iii). labour contributions:	....	....

CODES FOR WHAT HOUSEHOLD WOULD DO: 1. would contribute 2. would not pay but wait for others to pay

18. Are households currently monitoring each other on how they use grazing resources?

(i). the number of cattle owned.	0. no	1. yes
(ii). the people who are allowed to use community grazing resources.	0. no	1. yes
(iii). who contributes to grazing improvement.	0. no	1. yes

19. What do you think are the possible solutions to the overgrazing problem? ....

20. Over the period 1980 to 1995, on average what is your perception on the following:

(i). crop productivity? ....

(ii). milk output per cow per day? ....

(iii). draft power availability? ....

CODES: 1. increased 2. stayed the same 3. decreased 4. don't know

20.1 If, over time, there has been a decrease in any of the above, do you think it could have been due to overgrazing?

(i). crop productivity?	0. No	1. Yes
(ii). milk output per cow per day?	0. No	1. Yes
(iii). draft power availability?	0. No	1. Yes

20.2 If, over time, there has been a decrease in any of the above, do you think it could have been due to soil erosion?

(i). crop productivity?	0. No	1. Yes
(ii). milk output per cow per day?	0. No	1. Yes
(iii). draft power availability?	0. No	1. Yes

21. For how long have you been farming in this community?

1. < 1 year 2. 1 - 5 years 3. 5 - 10 years
4. 10 -20 years 5. > 20 years

THANK YOU FOR ANSWERING OUR QUESTIONS

ANNEX II: FOREIGN EXCHANGE RATES, 1989 – 1999

YEAR	EXCHANGE RATE: Z$:1US$
1989	2.126
1990	2.472
1991	3.752
1992	5.112
1993	6.529
1994	8.212
1995	8.724
1996	10.027
1997	12.444
1998	24.775
1999	38.338

ANNEX III: RECURSIVE LINEAR PROGRAMMING MODELS

Annex III.A: Linear Programming Model for Nerutanga

```
Title Nerutanga LP Model Final- With TGR, D = 0, YR4, Rainfall= 1123;

[Objective]     Max  =  -14.68*armzLg  -  14.68*armzSm  -  7.88*CatLULg  -
             7.88*CatLUSm - 7.38*OxInSm - 0.44*LabInLg + 0.44*LabOutSm +
             7.38*OxOutLg   -   GRPrice*TGRDem   +   GRPrice*TGRSuply   +
             0.09*MzSaleLg    +  0.09*MzSaleSm    +  117.60*CatSaleLg  +
             117.60*CatSaleSm + 0.42*MilkSaleLg + 0.42*MilkSaleSm;

[NetBenefitLg] GMLg  =   -14.68*armzLg  - 7.88*CatLULg - GRPrice*TGRDem -
             0.44*LabInLg   +   7.38*OxOutLg      +   0.09*MzSaleLg   +
             117.60*CatSaleLg + 0.42*MilkSaleLg;

[GMperHHLg]       GMpHHDLg = GMLg/NoHHDLg;

[NetBenefitSm]  GMSm  =  -  14.68*armzSm  -  7.88*CatLUSm  -  7.38*OxInSm  +
             0.44*LabOutSm   +   GRPrice*TGRSuply   +   0.09*MzSaleSm   +
             117.60*CatSaleSm + 0.42*MilkSaleSm;

[GMperHHSm]       GMpHHDSm = GMSm/NoHHDSm;


!Constraints;
!1. Herd Composition and Offtake Rates;
!1.1 Herd Composition and Productivity Data;
[CowPercent]      PercentCow = 0.336;
[OxPercent]       PercentOx = 0.292;
[MortCalf]        CalfMortPc = 0.05 + 0.0525*OpenHerdSD/RSD;
[MortAdult]       AdultMortPc = 0.03 + 0.0205*OpenHerdSD/RSD;
[CalvRate]        CalveRatePc = 0.75 - 0.234*OpenHerdSD/RSD;
[Cullrate]        CullratePc = 0.037;


!1.2 Opening Herd - Number of cattle owned;
[OpenHerdLg] CatLg = 88;
[OpenHerdSm] CatSm = 218;
[OpenHerdAll]  CatAll = CatLg + CatSm;


!1.3 Opening Herd - Number livestock units owned;
[OpenHdLULg] CatLULg = CatLg*0.8;
[OpenHdLUSm] CatLUSm = CatSm*0.8;
[OpenHdLUAll]  CatLUAll = CatAll*0.8;

!1.4 Herd Dynamics;
!1.4.1 Large Herd Owners;
[NewCalfLg]       CalvesLg = CatLg*PercentCow*CalveRatePc;
[CalfMtNoLg]      NCalfMortLg = CalvesLg*CalfMortPc;
[AdltMtNoLg]      NAdltMortLg = CatLg*AdultMortPc;
![CatLgSales]     CatSaleLg = CatLg*CullratePc;
[CloseHerdLg]     CloseCatLg = CatLg + CalvesLg - NCalfMortLg - NAdltMortLg
                  - CatSaleLg;
!1.4.2 Small Herd Owners;
[NewCalfSm]       CalvesSm = CatSm*PercentCow*CalveRatePc;
[CalfMtNoSm]      NCalfMortSm = CalvesSm*CalfMortPc;
[AdltMtNoSm]      NAdltMortSm = CatSm*AdultMortPc;
[CatSmSales]      CatSaleSm = CatSm*CullratePc;
[CloseHerdSm]     CloseCatSm = CatSm + CalvesSm - NCalfMortSm - NAdltMortSm
                  - CatSaleSm;
```

!1.5 Closing Herd;

```
[ClseHdLULg]      ClseCatLULg = CloseCatLg*0.8;
[ClseHdLUSm]      ClseCatLUSm = CloseCatSm*0.8;
[ClseHdAll]       ClseHerdAll = CloseCatLg + CloseCatSm;
[CloseHerdLUAll]  ClseHdLUAll = ClseHerdAll*0.8;
```

!2. Grazing Pressure and Carrying Capacity;

```
!Feed Available from the Rangelands kg DM;

[TotRangeFeed]    TARF = ((0.1 + 0.002714*Rain)*1000 - 200)*agrz;

!Feed Available from the Fields kg DM;
[MzFeedLg]        CFLg = armzLg*MZYildLg;
[MzFeedSm]        CFSm = armzSm*MZYildSm;

!Total Feed Available, kg DM;

[TotalFeed]       HAll = TARF + CFLg + CFSm;

!Carrying Capacity and Recommended Stoker Days per ha per year;

[CaryCapacity]    CC = HAll/FeedPerLU;

!Feed Requirement per year per LU, kg DM;

[LUFeed]          FeedPerLU = 8000;

!Recommended Stoker Days per Ha per Year;

[RecStkDays]      RSD*(agrz + armzLg + armzSm) = 365*CC;


!Actual SD per Ha per Year;
[OpenSD]    OpenHerdSD*(agrz + armzLg + armzSm) = 365*CatLUAll;
[CloseSD]   ClseHerdSD*(agrz + armzLg + armzSm) = 365*ClseHdLUAll;
```

!3. Milk Production Constraint;

```
!Milk yield per lactation (liters) is dependent on SD;
[MilkPerCow]      MilkYild = 298 - 205.9*OpenHerdSD/RSD;
[NoMilkCowLg]     NMlkCowLg = CalvesLg - NCalfMortLg;
[NoMilkCowSm]     NMlkCowSm = CalvesSm - NCalfMortSm;
[UseMilkLg]       - MilkYild*NMlkCowLg + MilkSaleLg <= 0;
[UseMilkSm]       - MilkYild*NMlkCowSm + MilkSaleSm <= 0;
```

!4. Draft Power Constraint;

```
!A Span Needs two Oxen;
[NoClseOxLg]      NoClseOxenLg = PercentOx*CloseCatLg;
[NoClseOxSm]      NoClseOxenSm = PercentOx*CloseCatSm;
[OxenSpanLg]      OxSpanLg = 0.5*NoClseOxenLg;
[OxenSpanSm]      OxSpanSm = 0.5*NoClseOxenSm;

!Number of days required to plow a hectare of land is dependent on SD;
!A pair of oxen can only be used during 44 days a year: mid - Nov - early
Jan for plowing;

[DraftSm]         OxInSm + 44*OxSpanSm - armzSm*plowrate >= 0;
[DraftLg]         44*OxSpanLg - OxOutLg - armzLg*plowrate >= 0;
[DraftEqm]        OxInSm = OxOutLg;
```

!A pair of oxen takes this number of days to plow a ha of land, depending on their condition which is dependent on the GP. As grazing pressure increases, the number of days to plow a ha of land increases;

```
[rateplow]        plowrate = 3 + 1.429*OpenHerdSD/RSD;
[DaysPlowLg]      PlowDayLg = armzLg*plowrate/OxSpanLg;
[DaysDelayLg]     DelayLg = PlowDayLg - 7;
[DaysPlowSm]      PlowDaySm = armzSm*plowrate/OxSpanSm;
[DaysDelaySm]     DelaySm = PlowDaySm - 7;
```

!5. Tradable Grazing right Constraint;
!Demand Function for Grazing Rights;

```
!Without TGR, Demand = Supply = 0;
![TGRDemandFunc]       TGRDem = 0;
![TGRSupplyFunc]       TGRSuply = 0;

[DemFunction]     TGRDem = 78.775 - 24.920*GRPrice;
```

!What is demanded is equal what will be supplied;

```
[SupFunction]     TGRSuply = TGRDem;
```

!Potential Number of Grazing Rights for Demand;

```
[PotGRDem]        GRPotDem = CatLuLg - NoHHDLg*CC/TotalHHD;
```

!Number of Grazing Rights not Demanded = No. cattle destocked;

```
[Destock]         CatDestock = GRPotDem - TGRDem;
```

!With TGR, cattle destocked is equal cattle sales by large herd owners, so freeze sales line by large herd owners under 1.4 above;

```
[CatLgSales]      CatSaleLg = CatDestock;
```

!6. Maize production function constraint;
!Maize yield (kg) functions are dependent on SD and Rec. SD relationship;

```
[MzYildFuncLg]    MzYildLg = 0.392*Rain + 40.442*ManFertLg -
                  20.855*OpenHerdSD/RSD;
[MzYildFuncSm]    MzYildSm = 0.392*Rain + 40.442*ManFertSm -
                 20.855*OpenHerdSD/RSD;
```

!Fertilizer and manure use are on a per ha basis;
!1LU produces about 2.92 kg of nitrogen per year;

```
[FertLg]          FertlzLg = 63.17;
[FertSm]          FertlzSm = 45.33;
[CatManLg]        ManureLg = 2.92*(ClseCatLULg + CatLULg)/(armzLg*2);
[CatManSm]        ManureSm = 2.92*(ClseCatLUSm + CatLUSm)/(armzSm*2);
[ManFertzLg]      ManFertLg = FertlzLg + ManureLg;
[ManFertzSm]      ManFertSm = FertlzSm + ManureSm;

![Rainfall]  Rain = 452;
![Rainfall]  Rain = 567;
![Rainfall]  Rain = 617;
![Rainfall]  Rain = 742;
![Rainfall]  Rain = 837;
```

```
![Rainfall]  Rain = 930;
[Rainfall]  Rain = 1123;

!Assume that all the maize produced is sold.  This way total production of
maize is valued;
[MzProdLg] MzYildLg*armzLg - MzSaleLg >= 0;
[MzProdSm] MzYildSm*armzSm - MzSaleSm >= 0;

!6.1 Land Constraints;
[LandTot] armzLg + armzSm + agrz <= 1575;
[LandUMzLg] armzLg <= 181.30;
![LandLMzLg] armzLg >= 153.67;
[LandUMzSm] armzSm <= 80.06;
![LandLMzSm] armzSm >= 67.86;


!7.  Labour Constraints;
[LaborEqm]        LabInLg = LabOutSm;

!Labour allocated to domestic activities;

[MenDomALg]       DomAMenLg = 0.125*260*MenLg;
[WmenDomALg]      DomAWmenLg = 0.33*260*WmenLg;
[ChnDomALg]       DomAChnLg = 0.0162*260*ChnLg;

[MenDomASm]       DomAMenSm = 0.125*260*MenSm;
[WmenDomASm]      DomAWmenSm = 0.33*260*WmenSm;
[ChnDomASm]       DomAChnSm = 0.0162*260*ChnSm;

!But crop production has to be done over a period of 3 months;

[CrpMLabLg] 23.44*armzLg    +    0.25*12*CatLULg    +    0.25*DomAMenLg    -
            0.25*260*MenLg - 0.5*LabInLg <= 0;

[CrpWLabLg]   23.44*armzLg   +   0.25*18.5*CatLULg   +   0.25*DomAWmenLg   -
            0.25*260*WmenLg - 0.5*LabInLg<= 0;

[CrpCLabLg] 11*armzLg + 0.25*DomAChnLg - 0.25*47.5*ChnLg <= 0;

[CrpMLabSm] 23.44*armzSm + 0.25*12*CatLULg + 0.25*DomAMenSm + 0.5*LabOutSm
            - 0.25*260*MenSm <= 0;
[CrpWLabSm]       23.44*armzSm   +   0.25*18.5*CatLULg   +   0.25*DomAWmenSm   +
            0.5*LabOutSm - 0.25*260*WmenSm <= 0;

[CrpCLabSm]       11*armzSm + 0.25*DomAChnSm - 0.25*47.5*ChnSm  <= 0;

[MEANHHSIZE]      HHSize = 3.8;
[HHDLg]           NoHHDLg = 49;
[HHDSm]           NoHHDSm = 83;
[HHtotal]         TotalHHD = NoHHDLg + NoHHDSm;

[NoMenLg]         MenLg = NoHHDLg*HHSize*0.25;
[NoWomenG4]       WmenLg = NoHHDLg*HHSize*0.333;
[NoChildG4]       ChnLg = NoHHDLg*HHSize*0.417;

[NoMenSm]         MenSm = NoHHDSm*HHSize*0.25;
[NoWomenSm]       WmenSm = NoHHDSm*HHSize*0.333;
[NoChildSm]       ChnSm = NoHHDSm*HHSize*0.417;

!8. Budget Constraints;
[BudConLg] -17.36*armzLg  -  9.4*CatLULg  -  GRPrice*TGRDem  -  0.44*LabInLg  +
           BudgetLg >= 0;
```

```
[BudConSm]   -17.36*armzSm - 9.4*CatLUSm - 7.91*OxInSm + BudgetSm >= 0;
[LgBudget]        BudgetLg = 3300;
[SmBudget]        BudgetSm = 3050;


!Without TGR;
![TGRPrice]   GRPrice = 0;

!With TGR;
![TGRPriceEqm]   GRPrice = 1.39;
![TGRPriceEp1]   GRPrice = 1.58;
[TGRPriceD0]   GRPrice = 3.13;


END
```

Annex III.B: Linear Programming Model for Gaza

```
Title Gaza LP Model Final - With TGR Base (0), Rainfall = 96;

[Objective]  Max = -11.4*armzLg - 11.4*armzSm - 11.7*CatLULg - 11.7*CatLUSm
              - 8.43*OxInSm - 0.44*LabInLg + 0.44*LabOutSm + 8.43*OxOutLg -
              GRPrice*TGRDem  +  GRPrice*TGRSuply  +  0.09*MzSaleLg   +
              0.09*MzSaleSm   +  90.78*CatSaleLg  +  90.78*CatSaleSm  +
              0.63*MilkSaleLg + 0.63*MilkSaleSm;

[NetBenefitLg] GMLg  =  -11.4*armzLg  -  11.7*CatLULg  -  GRPrice*TGRDem  -
                0.44*LabInLg  +  8.43*OxOutLg    +   0.09*MzSaleLg   +
                90.78*CatSaleLg + 0.63*MilkSaleLg;

[GMperHHLg]      GMpHHDLg = GMLg/NoHHDLg;

[NetBenefitSm]  GMSm  =  -  11.4*armzSm  -  11.7*CatLUSm  -  8.43*OxInSm  +
                 0.44*LabOutSm  +  GRPrice*TGRSuply  +  0.09*MzSaleSm  +
                 90.78*CatSaleSm + 0.63*MilkSaleSm;

[GMperHHSm]      GMpHHDSm = GMSm/NoHHDSm;
```

!Constraints;
!1. Herd Composition and Offtake Rates;
!1.1 Herd Composition and Productivity Data;

```
[CowPercent]      PercentCow = 0.365;
[OxPercent]       PercentOx = 0.302;
[MortCalf]        CalfMortPc = 0.05 + 0.0525*OpenHerdSD/RSD;
[MortAdult]       AdultMortPc = 0.03 + 0.0205*OpenHerdSD/RSD;
[CalvRate]        CalveRatePc = 0.75 - 0.234*OpenHerdSD/RSD;
[Cullrate]        CullratePc = 0.055;
```

!1.2 Opening Herd - Number of cattle owned;

```
[OpenHerdLg] CatLg = 318;
[OpenHerdSm] CatSm = 69;
[OpenHerdAll]  CatAll = CatLg + CatSm;
```

!1.3 Opening Herd - Number livestock units owned;

```
[OpenHdLULg] CatLULg = CatLg*0.8;
[OpenHdLUSm] CatLUSm = CatSm*0.8;
[OpenHdLUAll]  CatLUAll = CatAll*0.8;
```

!1.4 Herd Dynamics;
!1.4.1 Large Herd Owners;

```
[NewCalfLg]       CalvesLg = CatLg*PercentCow*CalveRatePc;
[CalfMtNoLg]      NCalfMortLg = CalvesLg*CalfMortPc;
[AdltMtNoLg]      NAdltMortLg = CatLg*AdultMortPc;
![CatLgSales]     CatSaleLg = CatLg*CullratePc;
[CloseHerdLg]     CloseCatLg = CatLg + CalvesLg - NCalfMortLg - NAdltMortLg
                  - CatSaleLg;
```

!1.4.2 Small Herd Owners;

```
[NewCalfSm]       CalvesSm = CatSm*PercentCow*CalveRatePc;
[CalfMtNoSm]      NCalfMortSm = CalvesSm*CalfMortPc;
[AdltMtNoSm]      NAdltMortSm = CatSm*AdultMortPc;
[CatSmSales]      CatSaleSm = CatSm*CullratePc;
[CloseHerdSm]     CloseCatSm = CatSm + CalvesSm - NCalfMortSm - NAdltMortSm
                  - CatSaleSm;
```

```
!1.5 Closing Herd;
[ClseHdLULg]       ClseCatLULg = CloseCatLg*0.8;
[ClseHdLUSm]       ClseCatLUSm = CloseCatSm*0.8;
[ClseHdAll]        ClseHerdAll = CloseCatLg + CloseCatSm;
[CloseHerdLUAll]  ClseHdLUAll = ClseHerdAll*0.8;

!2. Grazing Pressure and Carrying Capacity;
!Feed Available from the Rangelands kg DM;

[TotRangeFeed]     TARF = ((0.1 + 0.002714*Rain)*1000 - 200)*agrz;

!Feed Available from the Fields kg DM;
[MzFeedLg]         CFLg = armzLg*MZYildLg;
[MzFeedSm]         CFSm = armzSm*MZYildSm;

!Total Feed Available, kg DM;

[TotalFeed]        HAll = TARF + CFLg + CFSm;

!Carrying Capacity and Recommended Stoker Days per ha per year;

[CaryCapacity]     CC = HAll/FeedPerLU;

!Feed Requirement per year per LU, kg DM;

[LUFeed]           FeedPerLU = 8000;

!Recommended Stoker Days per Ha per Year;

[RecStkDays]       RSD*(agrz + armzLg + armzSm) = 365*CC;

!Actual SD per Ha per Year;
[OpenSD]           OpenHerdSD*(agrz + armzLg + armzSm) = 365*CatLUAll;
[CloseSD]          ClseHerdSD*(agrz + armzLg + armzSm) = 365*ClseHdLUAll;

!3. Milk Production Constraint;

!Milk yield per lactation (liters) is dependent on SD;
[MilkPerCow]  MilkYild = 185 - 26.33*OpenHerdSD/RSD;
[NoMilkCowLg]            NMlkCowLg = CalvesLg - NCalfMortLg;
[NoMilkCowSm]            NMlkCowSm = CalvesSm - NCalfMortSm;
[UseMilkLg]              - MilkYild*NMlkCowLg + MilkSaleLg <= 0;
[UseMilkSm]              - MilkYild*NMlkCowSm + MilkSaleSm <= 0;

!4.  Draft Power Constraint;
!A Span Needs two Oxen;
[NoClseOxLg]             NoClseOxenLg = PercentOx*CloseCatLg;
[NoClseOxSm]             NoClseOxenSm = PercentOx*CloseCatSm;
[OxenSpanLg]             OxSpanLg = 0.5*NoClseOxenLg;
[OxenSpanSm]             OxSpanSm = 0.5*NoClseOxenSm;


!Number of days required to plow a hectare of land is dependent on SD;
!A pair of oxen can only be used during 44 days a year: mid - Nov - early
Jan for plowing;

[DraftSm]          OxInSm + 44*OxSpanSm - armzSm*plowrate >= 0;
[DraftLg]          44*OxSpanLg - OxOutLg - armzLg*plowrate >= 0;
[DraftEqm]         OxInSm = OxOutLg;
```

```
!A pair of oxen takes this number of days to plow a ha of land, depending on their condition which is dependent on the GP.  As grazing pressure increases, the number of days to plow a ha of land increases;

[rateplow]        plowrate = 3 + 1.429*OpenHerdSD/RSD;
[DaysPlowLg]      PlowDayLg = armzLg*plowrate/OxSpanLg;
[DaysDelayLg]     DelayLg = PlowDayLg - 7;
[DaysPlowSm]      PlowDaySm = armzSm*plowrate/OxSpanSm;
[DaysDelaySm]     DelaySm = PlowDaySm - 7;
```

!5. Tradable Grazing right Constraint;

```
!Demand Function for Grazing Rights;

!Without TGR, Demand = Supply = 0;
![TGRDemandFunc]        TGRDem = 0;
![TGRSupplyFunc]        TGRSuply = 0;

[DemFunction]     TGRDem = 170.076 - 102.669*GRPrice;

!What is demanded is equal what will be supplied;

[SupFunction]     TGRSuply = TGRDem;

!Potential Number of Grazing Rights for Demand;

[PotGRDem]        GRPotDem = CatLuLg - NoHHDLg*CC/TotalHHD;

!Number of Grazing Rights not Demanded = No. cattle destocked;

[Destock]         CatDestock = GRPotDem - TGRDem;

!With TGR, cattle destocked is equal cattle sales by large herd owners, so freeze sales line by large herd owners under 1.4 above;

[CatLgSales]      CatSaleLg = CatDestock;
```

!6. Maize production function constraint;

```
!Maize yield (kg) functions are dependent on SD and Rec. SD relationship;

[MzYildFuncLg]         MzYildLg   =   0.184*Rain   +   20.861*ManFertLg   -
                        33.289*OpenHerdSD/RSD;

[MzYildFuncSm]         MzYildSm   =   0.184*Rain   +   20.861*ManFertSm   -
                        33.289*OpenHerdSD/RSD;


!Fertilizer and manure use are on a per ha basis;
!1LU produces about 2.92 kg of nitrogen per year;
[FertLg]          FertlzLg = 85.47;
[FertSm]          FertlzSm = 89.68;
[CatManLg]        ManureLg = 2.92*(ClseCatLULg + CatLULg)/(armzLg*2);
[CatManSm]        ManureSm = 2.92*(ClseCatLUSm + CatLUSm)/(armzSm*2);
[ManFertzLg]      ManFertLg = FertlzLg + ManureLg;
[ManFertzSm]      ManFertSm = FertlzSm + ManureSm;

!Rainfall distribution over a 44-year time period;

![Rainfall]  Rain = 96;
![Rainfall]  Rain = 256;
[Rainfall]  Rain = 449;
![Rainfall]  Rain = 541;
![Rainfall]  Rain = 652;
![Rainfall]  Rain = 749;
```

```
![Rainfall]  Rain = 940;
![Rainfall]  Rain = 1039;

!Assume that all the maize produced is sold.  This way total production of
maize is valued;

[MzProdLg] MzYildLg*armzLg - MzSaleLg >= 0;
[MzProdSm] MzYildSm*armzSm - MzSaleSm >= 0;
```

!6.1 Land Constraints;

```
[LandTot] armzLg + armzSm + agrz <= 1607;
[LandUMzLg] armzLg <= 207.9;
![LandLMzLg] armzLg >= 169.92;
[LandUMzSm] armzSm <= 146.88;
[LandLMzSm] armzSm >= 120.05;
```

!7. Labour Constraints;

```
[LaborEqm]         LabInLg = LabOutSm;

!Labour allocated to domestic activities;

[MenDomALg]        DomAMenLg = 0.125*260*MenLg;
[WmenDomALg]       DomAWmenLg = 0.33*260*WmenLg;
[ChnDomALg]        DomAChnLg = 0.0162*260*ChnLg;
[MenDomASm]        DomAMenSm = 0.125*260*MenSm;
[WmenDomASm]       DomAWmenSm = 0.33*260*WmenSm;
[ChnDomASm]        DomAChnSm = 0.0162*260*ChnSm;

!But crop production has to be done over a period of 3 months;

[CrpMLabLg]        23.44*armzLg   +   0.25*12*CatLULg   +   0.25*DomAMenLg   -
                   0.25*260*MenLg - 0.5*LabInLg <= 0;
[CrpWLabLg]        23.44*armzLg  +  0.25*18.5*CatLULg  +  0.25*DomAWmenLg  -
                   0.25*260*WmenLg - 0.5*LabInLg<= 0;
[CrpCLabLg]        11*armzLg + 0.25*DomAChnLg - 0.25*47.5*ChnLg <= 0;

[CrpMLabSm]        23.44*armzSm   +   0.25*12*CatLULg   +   0.25*DomAMenSm   +
                   0.5*LabOutSm - 0.25*260*MenSm <= 0;
[CrpWLabSm]        23.44*armzSm  +  0.25*18.5*CatLULg  +  0.25*DomAWmenSm  +
                   0.5*LabOutSm - 0.25*260*WmenSm <= 0;
[CrpCLabSm]        11*armzSm + 0.25*DomAChnSm - 0.25*47.5*ChnSm  <= 0;

[MEANHHSIZE]       HHSize = 4.4;
[HHDLg]            NoHHDLg = 74;
[HHDSm]            NoHHDSm = 88;
[HHtotal]          TotalHHD = NoHHDLg + NoHHDSm;

[NoMenLg]          MenLg = NoHHDLg*HHSize*0.25;
[NoWomenG4]        WmenLg = NoHHDLg*HHSize*0.333;
[NoChildG4]        ChnLg = NoHHDLg*HHSize*0.417;

[NoMenSm]          MenSm = NoHHDSm*HHSize*0.25;
[NoWomenSm]        WmenSm = NoHHDSm*HHSize*0.333;
[NoChildSm]        ChnSm = NoHHDSm*HHSize*0.417;
```

```
!8. Budget Constraints;
[BudConLg]    -17.36*armzLg - 9.4*CatLULg - GRPrice*TGRDem - 0.44*LabInLg +
               4900 >= 0;

[BudConSm]   -17.36*armzSm - 9.4*CatLUSm - 7.91*OxInSm + 4200 >= 0;


!Without TGR;
![TGRPrice]   GRPrice = 0;

!With TGR;
[TGRPriceEqm]   GRPrice = 1.39;
![TGRPriceEp1]   GRPrice = 1.65;
![TGRPriceD0]   GRPrice = 0.83;


END
```

Annex III.C: Linear Programming Model for Chiduku

```
Title Chiduku LP Model Final - With TGR, D = 0, YR1, RAINF = 1046;

[Objective]  Max = -16.29*armzLg - 16.29*armzSm - 9.4*CatLULg - 9.4*CatLUSm
              - 5.8*OxInSm - 0.44*LabInLg + 0.44*LabOutSm + 5.8*OxOutLg -
              GRPrice*TGRDem + GRPrice*TGRSuply + 0.09*MzSaleLg +
              0.09*MzSaleSm + 114.47*CatSaleLg + 114.47*CatSaleSm +
              0.79*MilkSaleLg + 0.79*MilkSaleSm;

[NetBenefitLg]  GMLg = -16.29*armzLg - 9.4*CatLULg - GRPrice*TGRDem -
                0.44*LabInLg + 5.8*OxOutLg + 0.09*MzSaleLg +
                114.47*CatSaleLg + 0.79*MilkSaleLg;

[GMperHHLg]       GMpHHDLg = GMLg/NoHHDLg;

[NetBenefitSm]  GMSm = - 16.29*armzSm - 9.4*CatLUSm - 5.8*OxInSm +
                0.44*LabOutSm + GRPrice*TGRSuply + 0.09*MzSaleSm +
                114.47*CatSaleSm + 0.79*MilkSaleSm;

[GMperHHSm]       GMpHHDSm = GMSm/NoHHDSm;
```

!Constraints;
!1. Herd Composition and Offtake Rates;
!1.1 Herd Composition and Productivity Data;

```
[CowPercent]      PercentCow = 0.272;
[OxPercent]       PercentOx = 0.338;
[MortCalf]        CalfMortPc = 0.05 + 0.0525*OpenHerdSD/RSD;
[MortAdult]       AdultMortPc = 0.03 + 0.0205*OpenHerdSD/RSD;
[CalvRate]        CalveRatePc = 0.75 - 0.234*OpenHerdSD/RSD;
[Cullrate]        CullratePc = 0.054;
```

!1.2 Opening Herd - Number of cattle owned;

```
[OpenHerdLg] CatLg = 277;
[OpenHerdSm] CatSm = 381;
[OpenHerdAll]  CatAll = CatLg + CatSm;
```

!1.3 Opening Herd - Number livestock units owned;

```
[OpenHdLULg] CatLULg = CatLg*0.8;
[OpenHdLUSm] CatLUSm = CatSm*0.8;
[OpenHdLUAll]  CatLUAll = CatAll*0.8;
```

!1.4 Herd Dynamics;
!1.4.1 Large Herd Owners;

```
[NewCalfLg]       CalvesLg = CatLg*PercentCow*CalveRatePc;
[CalfMtNoLg]      NCalfMortLg = CalvesLg*CalfMortPc;
[AdltMtNoLg]      NAdltMortLg = CatLg*AdultMortPc;
![CatLgSales]     CatSaleLg = CatLg*CullratePc;
[CloseHerdLg]     CloseCatLg = CatLg + CalvesLg - NCalfMortLg - NAdltMortLg
                  - CatSaleLg;
```

!1.4.2 Small Herd Owners;

```
[NewCalfSm]       CalvesSm = CatSm*PercentCow*CalveRatePc;
[CalfMtNoSm]      NCalfMortSm = CalvesSm*CalfMortPc;
[AdltMtNoSm]      NAdltMortSm = CatSm*AdultMortPc;
[CatSmSales]      CatSaleSm = CatSm*CullratePc;
[CloseHerdSm]     CloseCatSm = CatSm + CalvesSm - NCalfMortSm - NAdltMortSm
                  - CatSaleSm;
```

```
!1.5 Closing Herd;
[ClseHdLULg]       ClseCatLULg = CloseCatLg*0.8;
[ClseHdLUSm]       ClseCatLUSm = CloseCatSm*0.8;
[ClseHdAll]        ClseHerdAll = CloseCatLg + CloseCatSm;
[CloseHerdLUAll]   ClseHdLUAll = ClseHerdAll*0.8;

!2. Grazing Pressure and Carrying Capacity;
!Feed Available from the Rangelands kg DM;

[TotRangeFeed]     TARF = ((0.1 + 0.002714*Rain)*1000 - 200)*agrz;

!Feed Available from the Fields kg DM;
[MzFeedLg]         CFLg = armzLg*MZYildLg;
[MzFeedSm]         CFSm = armzSm*MZYildSm;

!Total Feed Available, kg DM;

[TotalFeed]        HAll = TARF + CFLg + CFSm;

!Carrying Capacity and Recommended Stoker Days per ha per year;

[CaryCapacity]     CC = HAll/FeedPerLU;

!Feed Requirement per year per LU, kg DM;

[LUFeed]           FeedPerLU = 8000;

!Recommended Stoker Days per Ha per Year;

[RecStkDays]       RSD*(agrz + armzLg + armzSm) = 365*CC;

!Actual SD per Ha per Year;
[OpenSD]           OpenHerdSD*(agrz + armzLg + armzSm) = 365*CatLUAll;
[CloseSD]          ClseHerdSD*(agrz + armzLg + armzSm) = 365*ClseHdLUAll;


!3. Milk Production Constraint;

!Milk yield per lactation (liters) is dependent on SD;
[MilkPerCow]  MilkYild = 285 - 106.91*OpenHerdSD/RSD;
[NoMilkCowLg]            NMlkCowLg = CalvesLg - NCalfMortLg;
[NoMilkCowSm]            NMlkCowSm = CalvesSm - NCalfMortSm;
[UseMilkLg]              - MilkYild*NMlkCowLg + MilkSaleLg <= 0;
[UseMilkSm]              - MilkYild*NMlkCowSm + MilkSaleSm <= 0;

!4.  Draft Power Constraint;
!A Span Needs two Oxen;
[NoClseOxLg]             NoClseOxenLg = PercentOx*CloseCatLg;
[NoClseOxSm]             NoClseOxenSm = PercentOx*CloseCatSm;
[OxenSpanLg]             OxSpanLg = 0.5*NoClseOxenLg;
[OxenSpanSm]             OxSpanSm = 0.5*NoClseOxenSm;
!Number of days required to plow a hectare of land is dependent on SD;
!A pair of oxen can only be used during 44 days a year: mid - Nov - early
Jan for plowing;

[DraftSm]          OxInSm + 44*OxSpanSm - armzSm*plowrate >= 0;
[DraftLg]          44*OxSpanLg - OxOutLg - armzLg*plowrate >= 0;
[DraftEqm]         OxInSm = OxOutLg;
```

!A pair of oxen takes this number of days to plow a ha of land, depending on their condition which is dependent on the GP. As grazing pressure increases, the number of days to plow a ha of land increases;

```
[RatePlow]        plowrate = 3 + 1.429*OpenHerdSD/RSD;
[DaysPlowLg]      PlowDayLg = armzLg*plowrate/OxSpanLg;
[DaysDelayLg]     DelayLg = PlowDayLg - 7;
[DaysPlowSm]      PlowDaySm = armzSm*plowrate/OxSpanSm;
[DaysDelaySm]     DelaySm = PlowDaySm - 7;
```

!5. Tradable Grazing right Constraint;
!Demand Function for Grazing Rights;

!Without TGR, Demand = Supply = 0;

```
![TGRDemandFunc]       TGRDem = 0;

![TGRSupplyFunc]       TGRSuply = 0;

[DemFunction]     TGRDem = 161.774 - 24.766*GRPrice;
```

!What is demanded is equal what will be supplied;

```
[SupFunction]     TGRSuply = TGRDem;
```

!Potential Number of Grazing Rights for Demand;

```
[PotGRDem]        GRPotDem = CatLuLg - NoHHDLg*CC/TotalHHD;
```

!Number of Grazing Rights not Demanded = No. cattle destocked;

```
[Destock]         CatDestock = GRPotDem - TGRDem;
```

!With TGR, cattle destocked is equal cattle sales by large herd owners, so freeze sales line by large herd owners under 1.4 above;

```
[CatLgSales]      CatSaleLg = CatDestock;
```

!6. Maize production function constraint;
!Maize yield (kg) functions are dependent on SD and Rec. SD relationship;

```
[MzYildFuncLg]       MzYildLg = 0.333*Rain + 29.614*ManFertLg - 182.652*OpenHerdSD/RSD;

[MzYildFuncSm]       MzYildSm = 0.333*Rain + 29.614*ManFertSm - 182.652*OpenHerdSD/RSD;
```

!Fertilizer and manure use are on a per ha basis;
!1LU produces about 2.92 kg of nitrogen per year;

```
[FertLg]          FertlzLg = 106.33;
[FertSm]          FertlzSm = 83.78;
[CatManLg]        ManureLg = 2.92*(ClseCatLULg + CatLULg)/(armzLg*2);
[CatManSm]        ManureSm = 2.92*(ClseCatLUSm + CatLUSm)/(armzSm*2);
[ManFertzLg]      ManFertLg = FertlzLg + ManureLg;
[ManFertzSm]      ManFertSm = FertlzSm + ManureSm;

![Rainfall]  Rain = 372;
![Rainfall]  Rain = 448;
![Rainfall]  Rain = 534;
![Rainfall]  Rain = 653;
```

```
![Rainfall]  Rain = 742;
![Rainfall]  Rain = 844;
![Rainfall]  Rain = 941;
[Rainfall]  Rain = 1046;


!Assume that all the maize produced is sold.  This way total production of
maize is valued;

[MzProdLg] MzYildLg*armzLg - MzSaleLg >= 0;
[MzProdSm] MzYildSm*armzSm - MzSaleSm >= 0;
```

!6.1 Land Constraints;

```
[LandTot] armzLg + armzSm + agrz <= 2512.5;
[LandUMzLg] armzLg <= 254.23;
![LandLMzLg] armzLg >= 201.91;
[LandUMzSm] armzSm <= 129.71;
[LandLMzSm] armzSm >= 103.02;
```

!7. Labour Constraints;

```
[MenDomALg]       DomAMenLg = 0.125*260*MenLg;
[WmenDomALg]      DomAWmenLg = 0.333*260*WmenLg;
[ChnDomALg]       DomAChnLg = 0.01*260*ChnLg;

[MenDomASm]       DomAMenSm = 0.125*260*MenSm;
[WmenDomASm]      DomAWmenSm = 0.333*260*WmenSm;
[ChnDomASm]       DomAChnSm = 0.01*260*ChnSm;

!But crop production has to be done over a period of 3 months;

[CrpMLabLg]       23.44*armzLg   +   0.25*12*CatLULg   +   0.25*DomAMenLg   -
                  0.25*260*MenLg
                   - 0.5*LabInLg <= 0;
[CrpWLabLg]       23.44*armzLg  +  0.25*18.5*CatLULg  +  0.25*DomAWmenLg  -
                  0.25*260*WmenLg
                   - 0.5*LabInLg<= 0;
[CrpCLabLg]       11*armzLg + 0.25*DomAChnLg - 0.25*47.5*ChnLg <= 0;

[CrpMLabSm]       23.44*armzSm   +   0.25*12*CatLULg   +   0.25*DomAMenSm   +
                  0.5*LabOutSm
                   - 0.25*260*MenSm <= 0;
[CrpWLabSm]       23.44*armzSm  +  0.25*18.5*CatLULg  +  0.25*DomAWmenSm  +
                  0.5*LabOutSm
                   - 0.25*260*WmenSm <= 0;
[CrpCLabSm]       11*armzSm + 0.25*DomAChnSm - 0.25*47.5*ChnSm  <= 0;

[MEANHHSIZE]      HHSize = 4.7;
[HHDLg]           NoHHDLg = 67;
[HHDSm]           NoHHDSm = 176;
[HHtotal]         TotalHHD = NoHHDLg + NoHHDSm;

[NoMenLg]         MenLg = NoHHDLg*HHSize*0.25;
[NoWomenG4]       WmenLg = NoHHDLg*HHSize*0.333;
[NoChildG4]       ChnLg = NoHHDLg*HHSize*0.417;

[NoMenSm]         MenSm = NoHHDSm*HHSize*0.25;
[NoWomenSm]       WmenSm = NoHHDSm*HHSize*0.333;
[NoChildSm]       ChnSm = NoHHDSm*HHSize*0.417;
```

!8. Budget Constraints;

```
[BudConLg]    -16.29*armzLg - 9.4*CatLULg - GRPrice*TGRDem - 0.44*LabInLg +
               BudgetLg >= 0;

[BudConSm]   -16.29*armzSm - 9.4*CatLUSm - 5.8*OxInSm + BudgetSm >= 0;

[LgBudget]        BudgetLg = 4910;

[SmBudget]        BudgetSm = 4800;


!Without TGR;
![TGRPrice]   GRPrice = 0;

!With TGR;
![TGRPriceEqm]   GRPrice = 2.33;
![TGRPriceEp1]   GRPrice = 3.27;
[TGRPriceD0]   GRPrice = 6.50;


END
```

Annex III.D: Linear Programming Model for Matsika

```
Title Matsika LP Model Final - With TGR Base (0), Rainfall = 318;

[Objective]  Max = -17.36*armzLg - 17.36*armzSm - 9.4*CatLULg - 9.4*CatLUSm
             - 7.91*OxInSm - 0.44*LabInLg + 0.44*LabOutSm + 7.91*OxOutLg -
             GRPrice*TGRDem + GRPrice*TGRSuply + 0.09*MzSaleLg +
             0.09*MzSaleSm + 135.63*CatSaleLg + 135.63*CatSaleSm +
             0.66*MilkSaleLg + 0.66*MilkSaleSm;

[NetBenefitLg]  GMLg = -17.36*armzLg - 9.4*CatLULg - GRPrice*TGRDem -
                0.44*LabInLg + 7.91*OxOutLg + 0.09*MzSaleLg +
                135.63*CatSaleLg + 0.66*MilkSaleLg;

[GMperHHLg]       GMpHHDLg = GMLg/NoHHDLg;

[NetBenefitSm]  GMSm = - 17.36*armzSm - 9.4*CatLUSm - 7.91*OxInSm +
                0.44*LabOutSm + GRPrice*TGRSuply + 0.09*MzSaleSm +
                135.63*CatSaleSm + 0.66*MilkSaleSm;

[GMperHHSm]       GMpHHDSm = GMSm/NoHHDSm;
```

!Constraints;

!1. Herd Composition and Offtake Rates;
!1.1 Herd Composition and Productivity Data;

```
[CowPercent]      PercentCow = 0.327;
[OxPercent]       PercentOx = 0.282;
[MortCalf]        CalfMortPc = 0.05 + 0.0525*OpenHerdSD/RSD;
[MortAdult]       AdultMortPc = 0.03 + 0.0205*OpenHerdSD/RSD;
[CalvRate]        CalveRatePc = 0.75 - 0.234*OpenHerdSD/RSD;
[Cullrate]        CullratePc = 0.072;
```

!1.2 Opening Herd - Number of cattle owned;

```
[OpenHerdLg] CatLg = 281;
[OpenHerdSm] CatSm = 145;
[OpenHerdAll]  CatAll = CatLg + CatSm;
```

!1.3 Opening Herd - Number livestock units owned;

```
[OpenHdLULg] CatLULg = CatLg*0.8;
[OpenHdLUSm] CatLUSm = CatSm*0.8;
[OpenHdLUAll]  CatLUAll = CatAll*0.8;
```

!1.4 Herd Dynamics;
!1.4.1 Large Herd Owners;

```
[NewCalfLg]       CalvesLg = CatLg*PercentCow*CalveRatePc;
[CalfMtNoLg]      NCalfMortLg = CalvesLg*CalfMortPc;
[AdltMtNoLg]      NAdltMortLg = CatLg*AdultMortPc;
![CatLgSales]     CatSaleLg = CatLg*CullratePc;
[CloseHerdLg]     CloseCatLg = CatLg + CalvesLg - NCalfMortLg - NAdltMortLg
- CatSaleLg;
```

!1.4.2 Small Herd Owners;

```
[NewCalfSm]       CalvesSm = CatSm*PercentCow*CalveRatePc;
[CalfMtNoSm]      NCalfMortSm = CalvesSm*CalfMortPc;
[AdltMtNoSm]      NAdltMortSm = CatSm*AdultMortPc;
[CatSmSales]      CatSaleSm = CatSm*CullratePc;
[CloseHerdSm]     CloseCatSm = CatSm + CalvesSm - NCalfMortSm - NAdltMortSm
- CatSaleSm;
```

!1.5 Closing Herd;

```
[ClseHdLULg]      ClseCatLULg = CloseCatLg*0.8;
[ClseHdLUSm]      ClseCatLUSm = CloseCatSm*0.8;
[ClseHdAll]       ClseHerdAll = CloseCatLg + CloseCatSm;
[CloseHerdLUAll]  ClseHdLUAll = ClseHerdAll*0.8;
```

!2. Grazing Pressure and Carrying Capacity;

```
!Feed Available from the Rangelands kg DM;

[TotRangeFeed]    TARF = ((0.1 + 0.002714*Rain)*1000 - 200)*agrz;

!Feed Available from the Fields kg DM;
[MzFeedLg]        CFLg = armzLg*MZYildLg;
[MzFeedSm]        CFSm = armzSm*MZYildSm;

!Total Feed Available, kg DM;

[TotalFeed]       HAll = TARF + CFLg + CFSm;


!Carrying Capacity and Recommended Stoker Days per ha per year;

[CaryCapacity]    CC = HAll/FeedPerLU;

!Feed Requirement per year per LU, kg DM;

[LUFeed]          FeedPerLU = 8000;

!Recommended Stoker Days per Ha per Year;

[RecStkDays]      RSD*(agrz + armzLg + armzSm) = 365*CC;

!Actual SD per Ha per Year;
[OpenSD]          OpenHerdSD*(agrz + armzLg + armzSm) = 365*CatLUAll;
[CloseSD]         ClseHerdSD*(agrz + armzLg + armzSm) = 365*ClseHdLUAll;
```

!3. Milk Production Constraint;

```
!Milk yield per lactation (liters) is dependent on SD;
[MilkPerCow]  MilkYild = 325 - 119.22*OpenHerdSD/RSD;
[NoMilkCowLg]           NMlkCowLg = CalvesLg - NCalfMortLg;
[NoMilkCowSm]           NMlkCowSm = CalvesSm - NCalfMortSm;
[UseMilkLg]             - MilkYild*NMlkCowLg + MilkSaleLg <= 0;
[UseMilkSm]             - MilkYild*NMlkCowSm + MilkSaleSm <= 0;
```

!4. Draft Power Constraint;

```
!A Span Needs two Oxen;
[NoClseOxLg]            NoClseOxenLg = PercentOx*CloseCatLg;
[NoClseOxSm]            NoClseOxenSm = PercentOx*CloseCatSm;
[OxenSpanLg]            OxSpanLg = 0.5*NoClseOxenLg;
[OxenSpanSm]            OxSpanSm = 0.5*NoClseOxenSm;

!Number of days required to plow a hectare of land is dependent on SD;
!A pair of oxen can only be used during 44 days a year: mid - Nov - early
Jan for plowing;

[DraftSm]         OxInSm + 44*OxSpanSm - armzSm*plowrate >= 0;
[DraftLg]         44*OxSpanLg - OxOutLg - armzLg*plowrate >= 0;
[DraftEqm]        OxInSm = OxOutLg;

!A pair of oxen takes this number of days to plow a ha of land, depending
on their condition which is dependent on the GP.  As grazing pressure
increases, the number of days to plow a ha of land increases;
```

```
[rateplow]          plowrate = 3 + 1.429*OpenHerdSD/RSD;

[DaysPlowLg]        PlowDayLg = armzLg*plowrate/OxSpanLg;
[DaysDelayLg]       DelayLg = PlowDayLg - 7;

[DaysPlowSm]        PlowDaySm = armzSm*plowrate/OxSpanSm;
[DaysDelaySm]       DelaySm = PlowDaySm - 7;
```

!5. Tradable Grazing right Constraint;

```
!Demand Function for Grazing Rights;

!Without TGR, Demand = Supply = 0;

![TGRDemandFunc]         TGRDem = 0;
![TGRSupplyFunc]         TGRSuply = 0;

[DemFunction]       TGRDem = 100.548 - 50.798*GRPrice;

!What is demanded is equal what will be supplied;

[SupFunction]       TGRSuply = TGRDem;

!Potential Number of Grazing Rights for Demand;

[PotGRDem]          GRPotDem = CatLuLg - NoHHDLg*CC/TotalHHD;

!Number of Grazing Rights not Demanded = No. cattle destocked;

[Destock]           CatDestock = GRPotDem - TGRDem;


!With TGR, cattle destocked is equal cattle sales by large herd owners, so
freeze sales line by large herd owners under 1.4 above;

[CatLgSales]        CatSaleLg = CatDestock;
```

!6. Maize production function constraint;

```
!Maize yield (kg) functions are dependent on SD and Rec. SD relationship;

[MzYildFuncLg]           MzYildLg   =   0.447*Rain   +   42.666*ManFertLg   -
                          131.236*OpenHerdSD/RSD;
[MzYildFuncSm]           MzYildSm   =   0.447*Rain   +   42.666*ManFertSm   -
                          131.236*OpenHerdSD/RSD;

!Fertilizer and manure use are on a per ha basis;
!1LU produces about 2.92 kg of nitrogen per year;
[FertLg]            FertlzLg = 96.56;
[FertSm]            FertlzSm = 95.46;
[CatManLg]          ManureLg = 2.92*(ClseCatLULg + CatLULg)/(armzLg*2);
[CatManSm]          ManureSm = 2.92*(ClseCatLUSm + CatLUSm)/(armzSm*2);
[ManFertzLg]        ManFertLg = FertlzLg + ManureLg;
[ManFertzSm]        ManFertSm = FertlzSm + ManureSm;

![Rainfall]  Rain = 318;
![Rainfall]  Rain = 451;
![Rainfall]  Rain = 532;
![Rainfall]  Rain = 644;
![Rainfall]  Rain = 751;
[Rainfall]  Rain = 845;
![Rainfall]  Rain = 944;
!Rainfall]  Rain = 1168;
```

```
!Assume that all the maize produced is sold.  This way total production of
maize is valued;

[MzProdLg] MzYildLg*armzLg - MzSaleLg >= 0;
[MzProdSm] MzYildSm*armzSm - MzSaleSm >= 0;

!6.1 Land Constraints;
[LandTot] armzLg + armzSm + agrz <= 1792.5;
[LandUMzLg] armzLg <= 179.07;
![LandLMzLg] armzLg >= 158.05;
[LandUMzSm] armzSm <= 117.17;
[LandLMzSm] armzSm >= 103.41;
```

!7. Labour Constraints;

```
[LaborEqm]        LabInLg = LabOutSm;

!Labour allocated to domestic activities;
[MenDomALg]       DomAMenLg = 0.125*260*MenLg;
[WmenDomALg]      DomAWmenLg = 0.33*260*WmenLg;
[ChnDomALg]       DomAChnLg = 0.0162*260*ChnLg;

[MenDomASm]       DomAMenSm = 0.125*260*MenSm;
[WmenDomASm]      DomAWmenSm = 0.33*260*WmenSm;
[ChnDomASm]       DomAChnSm = 0.0162*260*ChnSm;

!But crop production has to be done over a period of 3 months;
[CrpMLabLg]       23.44*armzLg  +  0.25*12*CatLULg  +  0.25*DomAMenLg  -
                  0.25*260*MenLg - 0.5*LabInLg <= 0;
[CrpWLabLg]       23.44*armzLg  +  0.25*18.5*CatLULg  +  0.25*DomAWmenLg  -
                  0.25*260*WmenLg - 0.5*LabInLg<= 0;
[CrpCLabLg]       11*armzLg + 0.25*DomAChnLg - 0.25*47.5*ChnLg <= 0;

[CrpMLabSm]       23.44*armzSm  +  0.25*12*CatLULg  +  0.25*DomAMenSm  +
                  0.5*LabOutSm - 0.25*260*MenSm <= 0;
[CrpWLabSm]       23.44*armzSm  +  0.25*18.5*CatLULg  +  0.25*DomAWmenSm  +
                  0.5*LabOutSm - 0.25*260*WmenSm <= 0;
[CrpCLabSm]       11*armzSm + 0.25*DomAChnSm - 0.25*47.5*ChnSm  <= 0;

[MEANHHSIZE]      HHSize = 4.1;
[HHDLg]           NoHHDLg = 45;
[HHDSm]           NoHHDSm = 116;
[HHtotal]         TotalHHD = NoHHDLg + NoHHDSm;

[NoMenLg]         MenLg = NoHHDLg*HHSize*0.25;
[NoWomenG4]       WmenLg = NoHHDLg*HHSize*0.333;
[NoChildG4]       ChnLg = NoHHDLg*HHSize*0.417;

[NoMenSm]         MenSm = NoHHDSm*HHSize*0.25;
[NoWomenSm]       WmenSm = NoHHDSm*HHSize*0.333;
[NoChildSm]       ChnSm = NoHHDSm*HHSize*0.417;
```

!8. Budget Constraints;

```
[BudConLg]    -17.36*armzLg - 9.4*CatLULg - GRPrice*TGRDem - 0.44*LabInLg +
               3425 >= 0;

[BudConSm]   -17.36*armzSm - 9.4*CatLUSm - 7.91*OxInSm + 2890 >= 0;


!Without TGR;
![TGRPrice]   GRPrice = 0;

!With TGR;
[TGRPriceEqm]   GRPrice = 0.58;
![TGRPriceEp1]   GRPrice = 0.99;
![TGRPriceD0]   GRPrice = 1.96;


END
```