CHAPTER 5

EFFECT OF RENOVATION ON IMPLEMENT PERFORMANCE, SOIL PHYSICAL CHARACTERISTICS AND AGRONOMIC PARAMETERS

This chapter is in two parts, 5.1 and 5.2. The first part deals with the effect of renovation on implement performance and the second part focuses on effect of implement renovation on soil physical characteristics and crop yields.

5.1 Effect of renovation on implement performance parameters

5.1.1 Introduction

Findings from the preceding chapter indicated that most smallholder farmers in the study areas owned poorly maintained implements and farmers removed some implement components due to lack of knowledge in correct use and maintenance.

The performance of an implement in carrying out a tillage operation is determined by operator skills, condition and setting of the implement, capacity of draught animals to pull, harnessing system used, level of training and willingness of animals to work, soil conditions and prevailing ambient conditions.

It was hypothesised that quality of work can be improved by using an implement that is correctly adjusted to suit field conditions and available draught to achieve desired soil conditions. Comparative tests to evaluate the performance of ploughs and cultivators in spring and winter seasons were conducted over two seasons, 1999-2000 and 2000-2001. Participating farmers had been nominated during focus group discussions (Chapter 4). The objective was to determine the

effect of repairing implements on the quality of work, implement performance and handling. Farmers' knowledge and skills in implements use and setting was also assessed.

5.1.2 Objective

The objective was to evaluate the performance of ploughs and cultivators before and after renovation in terms of depth and width of cut, draught, specific draught, field capacity, weeding efficiency, field efficiency, quality of work and implement handling.

5.1.3 Hypotheses of study

a) Renovation of implements results in better field efficiency, higher field capacity and improved weeding efficiency.
b) Implement renovation increases draught and reduces specific draught.
c) Renovation of implements improves quality of work resulting from deeper ploughing.
d) Renovated implements that are correctly set are easy to control and cause less stress on the operators.

5.1.4 Materials and methods

Inspection of a random sample of farmers' ploughs and cultivators was carried out to estimate the quantity of spares likely to be required to renovate ploughs and cultivators. Implement spares were procured and prices of spares were noted in order to monitor the trend in costs in the respective areas during the study period. Measuring instruments, equipment and tools that were used during implement testing and renovation are given in Table 5.1.

Table 5.1: Instruments and equipment used during implement performance tests

Name	Make	Model/Type	Size/Range	Purpose
Cylinder cores	Eijkelkamp		200 cm^3	Soil coring cylinder
Dictaphone	Philips	295 Pocket memo	30 min	Tape recording draught readings and any stoppages during work
Dry bulb thermometer	Zeal	High range Masons type	0-100 C	Ambient temperature measurement
Dutch auger			50 mm diameter	Soil texture sampling
Hand hoe		Steel	Small	Digging out soil core cylinders
Heart rate monitor	Polar Electro Oy	T61-coded	-	Plough operator heart rate
Load cell (Tension/Compression)	Tedea Huntleigh	No. 616	0-3000 N	Draught force measurement
Scale	EKS	EKS electronic-1002	0-2 kg	Core cylinder soil mass
Shear vane	Edeco Pilcon	Hand vane tester	19 mm vane, 0-120 kPa	Soil shear stress
Spanners	Diamond Brand	Combination	17, 19,22 mm	Undoing and tightening nuts and bolts
Split auger			25 mm diameter	Soil moisture sampling
Stop watch	Q&Q	Digital	-	Timing operations and stoppages
Theta Probe	Delta-T	ML-1	0-1 $m^3.m^{-3}$ full range	Volumetric soil moisture content
Theta Meter readout unit	Delta-T	HH1	0-1 $m^3.m^{-3}$ full range	Used with a Theta Probe to measure volumetric soil moisture content
Transducer readout unit (rechargeable)		RT-200	0-3000 N	Used with a load cell to measure draught force

Test plots

A test plot was identified at each household's farm site. The plot was split into two equal portions, plot A and B. Each portion measured 100 m long by 8 m wide as minimum dimensions. The farmer's implement (plough or cultivator) was tested in its original condition in plot A. After renovation the plough was tested in plot B. The test plots were marked out using 1-m long, 10 mm diameter steel pegs. Scratch marks were made to demarcate the plots using a test plough. Depending on the ploughing pattern preferred by the farmer, either gathering or casting, opening furrows were made in the test plots. Two pegs, 50 m apart, were placed in the middle-third of the opened furrows to be used for measuring the time taken by animals to cover 50 m so as to determine speed of operation. Two pegs were placed on each of the opening furrows at a distance of 20 m on

either side of the 50 m distance marked previously in order to mark datum points for taking width of cut measurements for each test run.

Soil sampling

Soil sampling for moisture content determination was done after marking out the test plots. Soil shear strength and bulk density measurements were taken after sampling for soil moisture content. Three replicates of soil samples, each weighing between 200 to 250 g at two depths of 0-150 mm and 150-300 mm, were taken in each plot using a split auger. Samples were placed in plastic sampling bags, sealed and taken for oven-dry moisture content determination by dry basis at the Soil and Water Conservation laboratory at Makoholi Research Station, Masvingo.

Four replicates of soil bulk density and shear strength were taken in each plot at 50, 100, 150, 200, 250 and 300 mm depths at each sampling station. Soil shear stress measurements were taken using a 19 mm diameter Edeco Pilcon hand vane tester. The shear vane tester was carefully pushed into the soil to each of the respective depths. The dial was turned until the soil sheared. Soil shear strength at the point of shear was indicated on the dial indicator and was recorded for each 50 mm depth interval up to 300 mm. Bulk density samples were taken very close to shear strengths sampling stations.

An Eijkelkamp cylinder core was carefully driven into the soil at each depth interval, avoiding any soil disturbance. A Delta-T ML-1 theta probe was inserted into the middle of the cylinder core and soil moisture in mV was recorded and the soil in the core was weighed using an EKS-electronic 1002 digital scale. Readings were recorded on a data sheet shown in Appendix 10. Volumetric soil water content (θ) used for bulk density calculations, was determined using the following expression (Delta-T Devices Ltd., 1999):

$$/\varepsilon = 1 + 19V^2 - 9.72V^3 + 24.35V^4 - 30.84V^4 + 14.73V^5$$

$$\text{Soil water content (SWC)} = a + b\,/\varepsilon \quad (m^3m^{-3})$$

where a = -0.1905, b=0.119 (a and b are calibration coefficients for standard calibration)

$/\varepsilon$ = the apparent dielectric constant of the soil

V = Volts (theta probe readings measured in millivolts)

Soil texture was determined from samples taken from three replicates at two depths of 0-150 mm and 150-300 mm in each test plot using a Dutch auger. Two composite samples made up of three 0-150 mm samples and three 150-300 mm samples were then used to determine soil texture. Samples for soil texture determination were air-dried and then subjected to the standard method for the mechanical analysis of soils to determine sand, silt and clay fractions (IAE, 1988).

Weeding efficiency

Initial soil surface description of each plot was noted before conducting plough tests. Weed infestation was determined by randomly throwing a 0.25 m^2 (0.5 m x 0.5 m) quadrant along the test plots to get five replicates for each sub-plot. Weeds inside the quadrant were counted before (W_1) and after ploughing or cultivating (W_2) and weeding efficiency was calculated using the following expression:

$$\text{Weeding efficiency} = [(W_1 - W_2)/W_1] \times 100\ (\%)$$

Draught potential of animals

Animal live weights were estimated from each animal's girth (G) and length (L) dimensions using the expressions (a) and (b) for cattle (Smith *et al*, 1994) and donkeys (Pearson and Ouassat, 2000),

respectively, indicated in Chapter 2, sub-section 2.3.1.3. A total live weight of each of the 53 draught teams was determined by summing up the individual weights of draught animals. A draught potential of 10% of the total weight was calculated for each draught team.

Specification of harnessing and traction systems

Harnessing systems used for each draught team and their respective specifications were recorded. Yoke specifications that included yoke shaft diameter, length of yoke shaft, position of skeis in relation to the centre of the yoke shaft and the centre distance between each pair of skeis were measured. Traction specification, particularly trek chain length, and height at yoke above ground were measured and the angle of pull was determined with the implement at operating depth, see Figure 2.2 under sub-section 2.3.2. Chain length adjustments and modifications made during tests were noted and subsequent changes in angles of pull were noted. Figure 5.1 shows yoke dimensions that were measured from all the yokes that were used with each draught team.

Figure 5.1: Dimensions measured on double neck yokes

All dimensions on the yoke were taken in mm and are described below:

A = length of yoke shaft
B = distance between skei centres
C1 = distance from yoke shaft centre to centre of left side skeis
C2 = distance from yoke shaft centre to centre of right side skeis
D1 = distance between left side skeis
D2 = distance between right side skeis
E = yoke shaft diameter

Specification of test implements

Test implements were weighed before and after reconditioning using a load cell. The mass of the plough was indicated on the load cell readout meter. Implement specifications that included type, make, model, and age were recorded.

Field performance of implements

After taking soil samples and plough specifications, plot A was ploughed using the farmer's typical practice, settings and adjustments. Starting and finishing times were noted respectively and any stoppages during ploughing were recorded using a Q&Q digital stop watch. Any stoppages and reasons for stopping were also noted.

Ploughing depth, width of cut, time taken to plough a distance of 50 m and draught were measured for each pass. Ten depth measurements were taken randomly along each furrow by placing a straight edge horizontally on the unploughed ground on the furrow wall and measuring the vertical distance from the furrow bottom to the straight edge using a steel measuring tape. Two widths of cut measurements were taken from the two datum steel pegs to the furrow wall for each pass using a measuring tape.

Draught readings were measured using a Tedea Huntleigh-No 616, tension/compression, load cell attached between the trek chain and the plough hitch point. A minimum of forty draught readings were recorded from five to ten ploughing runs per plot. Readings indicated on the load cell transducer read out meter were noted for the respective runs. Readings were called out and recorded using a battery-powered pocket Phillips-295 dictaphone. The dictaphone was played back after testing and draught readings were taken down manually onto a data sheet.

Field performance parameters that included draught, speed, ploughing depth and width, total time taken to plough each plot and the area ploughed were recorded on a data sheet. Work rate or field capacity for each paired plot was determined by dividing the area ploughed by the total time taken. Effective field capacity is a function of speed, width of cut and efficiency. These variables are related as shown by the expression below (Kepner *et al*, 1978):

$$\text{Field capacity (ha/hr)} = \frac{\text{speed (km/h) x width of cut (m) x field efficiency (\%)}}{10}$$

where, field efficiency = (theoretical work rate/actual work rate) x 100%

Draught recorded and work outputs were compared with theoretical values to ascertain if draught animals were working at their expected potential. Implement draught force requirements provided an indication of the level of workload to which draught animals were subjected during ploughing or cultivating. Ambient maximum temperatures were recorded at the start and at the end of each test using a Zeal dry bulb thermometer. A sample of the data sheet onto which implement performance variables were recorded is shown in Appendix 11. Figure 5.2 shows a typical ploughing operation at one of the test sites.

Figure 5.2: Ploughing and planting maize behind a plough: Mshagashe West-16.12.99

Mechanical weeding tests were conducted at two sites in the 2000-2001 season with RG1 households only. Weeding was done at about 3 to 4 weeks after crop emergence. Tests were conducted in the test plots that had been previously ploughed with the farmer's plough in its typical condition and after renovation, respectively. At each site, the farmer weeded plot A first with the cultivator in its original condition, settings and adjustments. Plot B was weeded after renovating the cultivator. Figure 5.3 shows mechanical weeding operation using a BS41 cultivator in a cotton crop.

Figure 5.3: Mechanical weeding with a BS41 cultivator in cotton: Chedenje-09.01.01

Implement renovation

After ploughing or weeding plot A, draught animals were stopped and rested. The test implement was unhitched and its condition was assessed. Initial implement assessment was done after ploughing plot A to ensure that the farmer had used the implement "as found" without being influenced by the testing team. The implement was renovated as described in Chapter 4, see subsection 4.4.14.

Thereafter plot B was ploughed or cultivated using the renovated implement using suitable settings and correct adjustments. The same draught animal team used before implement renovation was used. Field performance parameters were recorded similarly as in plot A. Quality of work, determined by soil inversion and crop residue or weed burial was assessed visually. Visual assessments and subjective comments by the implement operators on differences in quality of ploughing, implement handling and controlling were recorded after completing the tests.

Heart rate measurements of plough operators

Heart rates of operators during ploughing were recorded in the second winter ploughing season (2000-2001 season). A Polar Electro Oy™ T61-coded heart rate (HR) monitor was used to record the plough operators' HR characteristics during resting, working and recovery for comparisons to be made between test plots. The system uses sensors that detect electrical activity generated by the heart and a monitor dedicated to the sensors. Figure 5.4 shows an operator wearing the sensing system. HR readings, measured as heart pulses per minute, indicated the level of physiological stress due to workload on the operator. Specification of the plough operator i.e. sex, age, estimated body weight and arm length were noted on a data sheet shown in Appendix 12. HR readings of the operator were taken to obtain data on the easiness of implement handling, control and discomfort caused by the condition of the plough and settings. The elevation of working HR above resting HR before and after plough renovation was determined for 12 operators. HR elevation was expressed as a function of resting HR using the following expression:

$$[(\text{Working HR}-\text{Resting HR})]/\text{Resting HR}$$

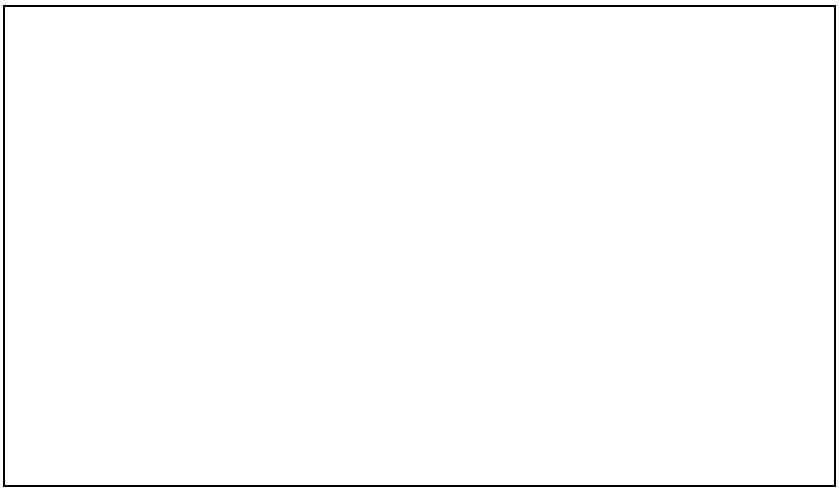

Figure 5.4: A plough operator wearing heart rate sensing equipment: Nyimai-22.06.01

Data analysis

Raw data were captured in Excel spreadsheets (Microsoft Corporation, 1997) and measured variables were appropriately coded to be read by the Statistical Analysis System (SAS) software (SAS Institute Inc, 1996).

The main data sets comprising class and continuous variables were converted from spreadsheets to SAS files. Correlation analyses of plough and cultivator performance data were run so as to establish variables with high correlations. This was done to eliminate some variables which were closely associated with each other and avoid inaccurate prediction of the dependent variable to be analysed in the models. The inclusion of highly correlated independent variables in General Linear Models (GLMs) would result in inaccurate estimates of regression coefficients normally caused by collinearity (Dilorio, 1991).

Dependent variables were assigned respective independent variables. For example if draught was the dependent variable to be analysed, three or so independent variable that influence draught, such as depth, speed and plough defects, were used in the model to analyse draught. The independent variables formed what is known as a class in the SAS procedures. Class variables for each dependent variable were determined as required by the SAS system and analyses of variance (ANOVA) were carried out for the respective dependent variables. GLMs were used for the ANOVA tests. GLM is one of the SAS procedures that computes ANOVA for data in unbalanced designs. One way ANOVA, with treatment as the independent variable, was run for all performance parameters to determine how implement renovation influenced these parameters.

5.1.5 Results

5.1.5.1 Draught animal teams

Households used draught animal teams with different compositions during the trials. The majority of draught teams (89%) were composed of four animals while 11% had two animals. Draught teams with at least a donkey accounted for 11% of spans and were mainly used by poor-resourced households. The rest were cattle spans used by all resource groups. The majority (75%) of draught teams had cows. About 40% of draught teams had a cow-oxen combination cutting across all resource groups and 43% of draught teams had balanced numbers of cows and oxen, i.e. 2 cows and 2 oxen in a team. Only one household used a four-donkey draught team. Draught teams with two or four-oxen constituted 9% each, of the total teams and these were mainly used by the well-resourced households. Teams with bulls accounted for about 21% of the total number of teams. About 11% of the draught teams were hired or borrowed by resource-poor households (RG3 and 4). Figures 5.5 and 5.6 show the type of draught animals that made up draught teams during implement performance trials.

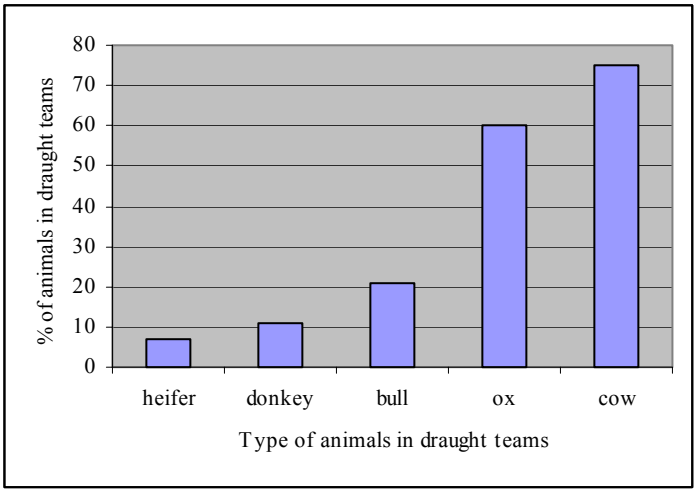

Figure 5.5: Types of draught animals used by households

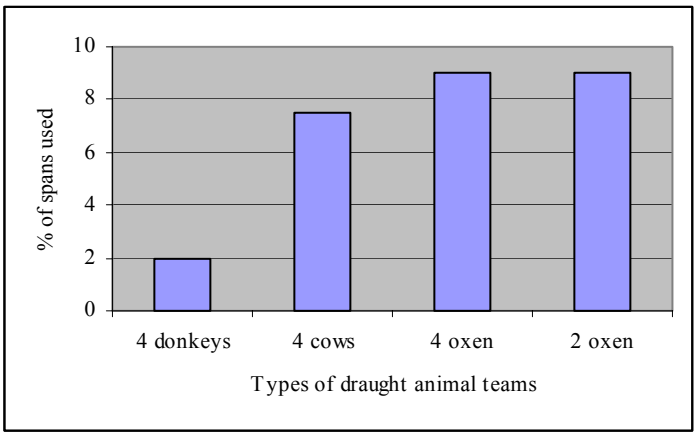

Figure 5.6: Single-type of draught animal teams used by households

5.1.5.2 Draught potential of spans

Draught potential of animals was estimated to be 10% of the combined weight of animals in each team. Draught potential was 0.79 kN and 1.13 kN for two-animal and four-animal teams, respectively. One four-donkey team had a draught potential of 0.54 kN. The mean live weight of each animal in two-animal and four-animal cattle spans was 403 kg and 288 kg, respectively while each donkey had a mean live mass of 123 kg.

5.1.5.3 Harnessing and hitching systems used in the trials

Double neck yokes were used to harness draught animal spans including spans that had donkeys. Farmers did not use correct donkey harnessing systems. The means of the plough yoke shaft diameter and length were 72 mm and 1309 mm, respectively. The mean skei centre distance was 772 mm while the mean distance between skeis was 247 mm. Farmers used yokes that had varying specifications. Results showed significant ($P<0.0001$) differences in yoke dimensions. The mean trek chain lengths for farmer-set and modified system were 2.8 m (ranging from 2 m to 3.65 m) and 3 m (ranging from 2.38 m to 3.65 m), respectively. Cultivator yoke shafts had a mean length of 2.33 m and shaft diameter of 78 mm. Distance between skeis was 265 mm while the mean skei centre distance was 1.71 m. Examples of how some farmers harnessed donkeys during ploughing are shown in Appendix 12.

5.1.5.4 Plough performance

The prevailing maximum dry bulb ambient temperatures recorded during spring ploughing tests ranged from 20°C to 34°C (mean of 27°C). In winter temperatures ranged from 17°C to 24°C (mean of 21°C). Results of the analysis of variables measured during testing are summarised in Appendices 13 and 14. An analysis of individual variables measured during tests is presented below.

Draught was one of the important variables measured to compare the performance of the plough before and after renovation. The resultant draught in a tillage system is a function of the implement-soil characteristics. Factors that make up the implement-soil system include soil conditions, surface texture, depth and speed of operation, geometry and orientation of the implement.

A mean increase of 24% in draught was recorded after plough renovation. A one way ANOVA showed that the mean draught recorded after renovation (1.09 kN) was significantly higher (P<0.0001) than that recorded before renovation (0.88 kN). An analysis of variance for draught is given in Table 5.2. Depth, speed of work, plough mass, defects and speed-depth interaction were significant (P<0.0001) in predicting draught. The minimum and maximum values of draught recorded, in all test plots, were 0.343 kN and 1.857 kN, respectively. Mean specific draught recorded before and after renovation was 3.3 N/cm^2 and 2.9 N/cm^2, respectively. A significant (P<0.0001) reduction in specific draught was observed after implement renovation due to an increase in area of the furrow slice as a result of an increase in working depth.

Table 5.2: ANOVA for draught during ploughing

Dependent Variable: DRAUGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	69	18499713.05809990	268111.78345072	93.01	0.0001
Error	214	616877.37499868	2882.60455607		
Corrected Total	283	19116590.43309850			

R-Square	C.V.	Root MSE	DRAUGHT Mean
0.967731	5.465149	53.68989249	982.40492958

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DEPTH	4	126642.11607149	31660.52901787	10.98	0.0001
SPEED	1	61616.62759514	61616.62759514	21.38	0.0001
SPEED*DEPTH	2	121246.93052649	60623.46526324	21.03	0.0001
PLOUGH DEFECTS	8	2831034.35714285	353879.29464286	23.23	0.0001
PLOUGH MASS	46	9768402.62083333	212356.57871377	13.94	0.0001
MC	1	10302.25470476	10302.25470476	3.86	0.0515

A typically farmer-set plough worked at a mean depth of 92 mm. After renovation the mean ploughing depth was 128 mm. Depth of ploughing significantly increased (P<0.0001) after plough renovation. Table 5.3 shows that plough mass and defects were significant (P<0.0001) while bulk density, soil moisture and shear stress were significant (P<0.05) in predicting depth of ploughing.

Table 5.3: ANOVA for depth of ploughing

Dependent Variable: DEPTH OF PLOUGHING

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	61	191188.08959617	3134.23097699	24.89	0.0001
Error	262	32993.58478409	125.92971292		
Corrected Total	323	224181.67438026			

R-Square	C.V.	Root MSE	DEPTH Mean
0.852827	9.800713	11.22184089	114.50024691

Source	DF	Type III SS	Mean Square	F Value	Pr > F
PLOUGH DEFECTS	10	31454.28154731	3145.42815473	24.98	0.0001
PLOUGH MASS	44	80645.62994317	1832.85522598	14.55	0.0001
MOISTURE CONTENT	1	696.63724811	696.63724811	5.53	0.0194
SHEAR STRESS	1	629.66420174	629.66420174	5.00	0.0262
BULK DENSITY	1	1352.24139403	1352.24139403	10.74	0.0012

Ploughing width increased significantly (P<0.0001) by 13 mm after reconditioning ploughs. Plough defects were significant in predicting width of cut. Soil physical characteristics did not influence working width of ploughs. Width of cut was moderately negatively correlated to specific draught (r =-0.48).

After plough renovations, ploughing speed decreased by 7%. Speed of operation in plot A ranged from 2.39 to 5.47 km/hr. In plot B, speed ranged from 2.49 to 5.42 km/hr. Mean speeds achieved with farmer-set ploughs and reconditioned ploughs were 4.12 km/hr and 3.86 km/hr, respectively. Speed of operation was significantly (P<0.0001) influenced by plough defects, depth of ploughing and draught potential of draught animal teams. Results showed that speed decreased significantly (P<0.0001) after renovation.

A decrease in speed, coupled with an increase in width of work, did not influence rate of work after plough renovation. Mean work rates were the same (0.09 ha/hr or 11.11 hr/ha) for both farmer-set and the renovated ploughs. This is equivalent to 0.54 ha/6-hour day. Analysis of variance for work rate showed that speed, width and field efficiency were significant (P<0.01) in predicting work rate. The means of field efficiencies before and after renovation were 85% and 86%, respectively. There were no significant differences in field efficiency when working with unrenovated and renovated ploughs.

As depth of ploughing increased after reconditioning ploughs, weeding efficiency improved. Results showed that both depth of work and plough defects were significant (P<0.0001) in determining weeding efficiency (Table 5.4). The mean weeding efficiency of renovated ploughs (86%) was significantly (P<0.0001) better than that of farmer-set ploughs (71%).

Table 5.4: ANOVA for weeding efficiency during ploughing

Dependent Variable: WEEDING EFFICIECY					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	98	83103.44761905	847.99436346	210.75	0.0001
Error	321	1291.60000000	4.02367601		
Corrected Total	419	84395.04761905			
	R-Square	C.V.	Root MSE	WEEDEFF Mean	
	0.984696	2.551430	2.00591027	78.61904762	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
PLOUGH DEFECTS	6	3535.06666667	589.17777778	146.43	0.0001
DEPTH	84	42815.98974359	509.71416361	126.68	0.0001

5.1.5.5 Heart rate measurements of plough operators

The elevation of working HRs for twelve operators using ploughs at different sites under varying field conditions before and after plough renovation are given in Figure 5.7. A mean reduction in heart rate of 5% was recorded after renovation. Results showed no significant difference (P=0.7956) in HR before and after renovation (128 pulses/minute in plot A and 127 pulses/minute in plot B). Speed of work was significant (P=0.0144) while plough defects and depth of work were significant (P<0.0001) in determining operator HR even though there was low correlation between these variables and HR. A typical illustration of the workload on the operator before and after renovation at one of the farm sites is given in Figure 5.8.

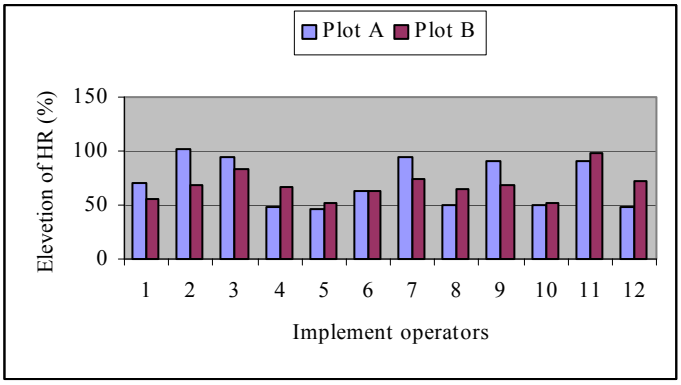

Figure 5.7: Elevation of working HR above resting HR

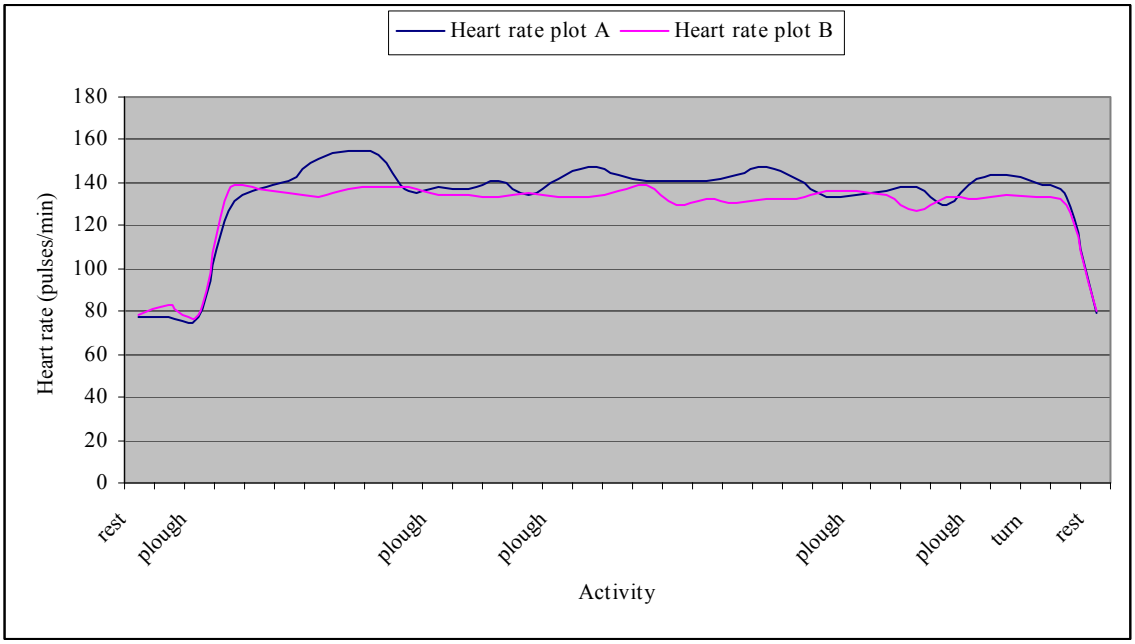

Figure 5.8: Heart rate of plough operator recorded in plot A and B at one test site-Mutangi: 05.07.01
Rest=operator's heart rate recorded while operator was sited before and after ploughing
Plough=operator's heart rate recorded while ploughing
Turn= operator's heart rate recorded while turning at headlands

5.1.5.6 Cultivator performance

The mean draught potential of two-animal spans used during weeding was 0.84 kN. After renovation draught increased by 9%. There was a significant difference ($P<0.0076$) in mean draught recorded in plot A (0.506 kN) and in plot B (0.553 kN). Table 5.5 shows that speed and depth were significant in determining draught for weeding.

Table 5.5: ANOVA for draught during weeding

Dependent Variable: DRAUGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	64025.38563049	32012.69281525	18.59	0.0001
Error	37	63703.01436951	1721.70309107		
Corrected Total	39	127728.40000000			

R-Square	C.V.	Root MSE	DRAUGHT Mean
0.501262	7.833379	41.49341021	529.70000000

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DEPTH	1	51462.73198761	51462.73198761	29.89	0.0001
SPEED	1	25914.40129870	25914.40129870	15.05	0.0004

Mean depth readings were 64 mm and 73 mm for plot A and B, respectively. Depth increased significantly (P<0.0001) after renovation. Depth of work was highly correlated to defects (r =-0.63), mass (r = -0.85) and speed (r = 0.91). Plough defects were significant (P<0.0001) in predicting depth of work. There was no significant difference between the mean working widths achieved before (553 mm) and after (541 mm) renovation. Defects were not significant (P=0.74) in predicting width of work.

The mean speeds of work for plot A and B were 3.6 km/hr and 4.2.km/hr. The difference in speed was significant (P<0.01) and there was a significant (P<0.0001) effect of defects and depth in the prediction of speed. Speed was highly correlated to depth of work (r = 0.91) and field efficiency (r = -0.86).

The mean work rates before and after renovation were 0.24 ha/hr (4.2 hr/ha) and 0.27 ha/hr (3.7 hr/ha), respectively. An increase of 13% in work rate was recorded in plot B. The increase was significant (P<0.0001) after renovation. Speed and cultivator defects were important sources of variation and significant (P<0.0001) while width was significant (P<0.05) in predicting work rate. Work rate was highly correlated to field efficiency (r = -0.68) and weeding efficiency (r = -0.71).

Mean field efficiencies obtained in plots A and B were 82% and 84% respectively and there was no significant (P=0.7685) difference between paired plots. Speed was significant (P<0.0001) in

predicting field efficiency while width of work was not (P>0.05). Field efficiency was highly correlated to depth, speed, work rate and moderately correlated to width of work.

The renovated cultivator achieved a significantly (P<0.0001) higher weeding efficiency. Mean weeding efficiency achieved before and after renovation was 48% and 86%, respectively, giving a 79% increase after renovation. Width, depth and defects were significant in predicting weeding efficiency as shown in Table 5.6.

Table 5.6: ANOVA for weeding efficiency of cultivator

Dependent Variable: WEEDING EFFICIENCY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	12688.82904782	4229.60968261	61.93	0.0001
Error	36	2458.67095218	68.29641534		
Corrected Total	39	15147.50000000			

R-Square	C.V.	Root MSE	WEEDEFF Mean
0.837685	12.38077	8.26416453	66.75000000

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DEPTH	1	389.24253476	389.24253476	5.70	0.0223
WIDTH	1	709.49010911	709.49010911	10.39	0.0027
DEFECTS	1	8952.34243061	8952.34243061	131.08	0.0001

5.1.6 Discussion

Cattle were commonly used during tests and the majority of households used four animals while only 11% used two animals. Donkeys were rarely used suggesting a preference for cattle for draught work even for households that owned both cattle and donkeys. Most draught teams had female animals mostly cows and few had heifers.

The trials demonstrated that all spans were capable of pulling the plough before and after renovations though the renovated plough weighed more than before renovation. The draught requirement of the renovated plough was therefore within the pulling capacity of draught teams. The average draught animal (cattle) weighed about 288 kg which was less than the optimum weight (500 kg) of a draught animal (IAE, 1986b).

Traction and hitching systems i.e. yokes, skeis and trek chains did not comply with recommended specifications. There was a wide range of yoke specifications with the majority of them having dimensions that were less than the recommended specifications. The recommended skei centre distances for a plough and a cultivator yoke are 900 mm and 1800 mm, respectively. Spacing between skeis should be 280 mm for both types of yoke but can be adjusted to suit animal sizes. The standard length of a plough and a cultivator yoke shaft is 1500 mm and 2400 mm, respectively while the shaft diameter is 80 mm (IAE 1986b). Cattle yokes were used to harness donkeys. Not only does the practice waste energy, it is uncomfortable and causes injuries to donkeys (Barwell and Ayre, 1982; Jones, 1977). The traditional cattle yokes are inappropriate for donkeys because the pulling strength of donkeys is in the breast rather than in the withers.

Even though speed and moisture content were weakly and positively correlated to draught, they both have a significant influence on draught. Draught increases with increased forward speed due to more rapid acceleration of soil (Spoor, 1969; Kepner *et al*, 1978). Soil moisture influences soil-soil and soil-metal parameters which in turn influences draught. For example, in sandy soils found in Mshagashe, moisture softened and loosened soil and the resultant draught was lower than in more sticky conditions experienced in sandy clay loam soils in Mushandike.

As expected, penetration characteristics of ploughs improved after renovation. The mean ploughing depth achieved using farmer-set ploughs were consistent with findings by Francis, (1993) that smallholder farmers plough at shallow depths not exceeding 150 mm. The IAE recommends a ploughing depth of 200 mm (IAE, 1986b), for the standard plough, but most draught animals did not have the capacity to sustain high draught associated with deep ploughing.

Lower specific draught readings were recorded after renovation due to an increase in the area of the furrow slice that was cut after plough renovation. These values fell within limits given by Kepner, *et al* (1978). The differences in draught observed before and after renovation are attributed to the area of the furrow slice (depth x width of ploughing), plough mass and changes in implement geometry caused by plough defects.

Speed of operation is affected by factors such as draught potential of work animals, whether animals are trained or not, willingness of animals to work, depth and width of work, soil and field conditions, setting and condition of the implement. Forward speeds for unrenovated and renovated ploughs showed that draught animals worked at faster rates than the normally expected speed of 1 m/s for sustainable work output during ploughing (IAE, 1985). Normally, forward speed should be comfortable for both work animals and operators and this can be achieved through correct training of animals and operators. The shallow depth of ploughing achieved was a factor that influenced the higher speeds of work. Results showed that speed, width of cut and field efficiency were significant in work rate prediction.

Weeding efficiency was determined to compare the effects of plough performance on weed burial before and after renovation. Increased weeding efficiency after plough renovation was attributable to improved penetration resulting in better soil inversion and weed burial. Improved weed burial meant that the hand weeding burden, that is associated with poor quality of ploughing, would be reduced leaving fields with relatively less weeds and enabling a good environment for improved crop growth. It is therefore beneficial for farmers to achieve good quality of seedbed preparation and eradicate weeds by deep ploughing prior to planting so as to ease the burden of weeding. Deep ploughing also improves crop yields (Grant, 1968).

Possibly due to a small sample size, the mean reduction in elevation of operators' HRs was not significant after plough renovation. This reduction in the dynamic work load on operators after renovation, though small, was due to correct setting that improved the stability of the reconditioned ploughs. Results showed that working HRs of plough operators, before and after renovation, did not exceed twice their respective resting HRs for sustainable work (Smith *et al*, 1994). Should the HRs exceed twice the resting HRs, the operators would be over-stressed by the work load.

The opinion expressed by most plough operators, though subjective, testify that renovated ploughs were easier to handle and control. Visual assessments of the ploughing operations revealed that operators did not experience difficulties in controlling renovated ploughs. Ideally, a well-set mouldboard plough should be stable, cutting a clean surface on the furrow wall and bottom (Culpin, 1981).

Although draught increased after reconditioning cultivators, draught animals worked between 60% and 80% of their pulling capability. The maximum draught recorded during mechanical weeding was equivalent to 36% and 67% of the maximum and mean draught of ploughing, respectively. Draught demand for weeding was therefore lower than that for ploughing.

Weeding depth achieved after renovation was slightly more than the initial depth achieved using farmer-settings. Unlike with ploughs, cultivator defects were not significant in predicting width of work. Weeding speed increased after renovation and consequently draught increased, as expected. Increase in speed improved field capacity although there was no significant difference in field capacities before and after renovation.

5.1.7 Conclusion

As was correctly hypothesised, results indicated that reconditioning and correct setting of implements improved field performance, weeding efficiency, field efficiency and field capacity. Renovation of implements increased draught but reduced specific draught. Despite the increase in draught after renovation, as correctly perceived by farmers, draught requirement of implements was within pulling capabilities of draught animals. It is however technically incorrect to remove parts such as hitch assemblies to reduce draught because proper settings will no longer be possible and ploughs become difficult to control.

The most important benefit of plough renovation was increased depth of ploughing, increased weeding and field efficiencies.

Renovation, improved implement stability control and handling of resulting in better and efficient use of limited DAP. The performance of implements that were in poor condition compromised the quality of work that is desirable in achieving the primary objectives of tillage during conventional ploughing and weed control.

Traction and hitching systems used by farmers did not conform to standard specifications for optimum use of energy produced by draught animals and wastes scarce DAP. Renovated implements used with suitable and correct settings and adjustments were easier for operators to handle and control. The hypotheses that renovation and correctly set implements are easy to use and control can be accepted. The common opinion expressed by most plough operators, though subjective, testify that renovated ploughs were easier to control and handle.

5.2 Effect of implement renovation on soil physical characteristics and crop performance

5.2.1 Introduction

Comparative tests to determine the effect of repairing implements on soil characteristics as well as on maize and cotton yield were conducted over two growing seasons 1999-2000 and 2000-2001 with the same set of test plots described in Chapter 5.1

Findings from Chapter 5.1 showed that most ploughs used with farmers' usual settings worked at shallower depth than the renovated ploughs. The quality and uniformity of tillage produced by renovated ploughs was also better in terms of the resultant tilth. Good soil tilth is an important factor in seedbed preparation as it allows free movement of air and water and provides a good seed-soil contact. Better quality of work was as a result of correct setting, deeper ploughing and stability of the renovated plough. The extent to which unrenovated and renovated ploughs disturbed soil varied in the test plots. Soil physical characteristics such as bulk density, shear strength and moisture were expected to vary between plots ploughed before and after renovation and influence the performance of crops grown and yields.

5.2.2 Objectives

The objective of the study was to investigate the effect of renovating ploughs and cultivators on three soil physical properties (soil bulk density, soil shear stress and soil moisture) and crop yield.

5.2.3 Hypotheses of study

a) Renovation of ploughs and cultivators reduces soil shear stress, soil bulk density and improves soil moisture content.
b) The use of renovated ploughs and cultivators improves crop yields.

5.2.4 Materials and methods

Trials plots

Test plots that were used in this study were the same as the ones used during implement performance evaluations and so the marking out and soil sampling followed the same procedure as described in Chapter 5.1.

Crop establishment and management

Maize or cotton were planted in paired plots ploughed before and after renovation, depending on which crop each farmers had selected to grow. Maize and cotton seed varieties planted were SC 5201 and FQ 902, respectively. Planting and all subsequent field operations carried out, resource allocation and inputs used were the responsibility of the respective households. Each household was given a crop budget data sheet onto which details of planting date, all operations carried out after ploughing and resources used were recorded throughout the season until harvest. A sample of the crop budget is shown in Appendix 16.

Monitoring crop growth and soil physical characteristics

Plant populations in the plots were estimated at emergence by counting plants in the rows. Counts of plants per 2-m length of crop rows were taken at five positions in each plot. Crop row spacing was measured at five positions corresponding to positions where plant counts were taken. The means of plant counts per metre and row spacing were determined and plant populations were estimated for the paired plots at each site.

Soil moisture, bulk density and shear strength were taken on monthly intervals after the date of ploughing to assess any changes in soil physical characteristics. Crop height measurements were

taken at the same intervals as for soil measurements to monitor and assess crop development. Crop yields from all paired plots were measured at the end of the season and compared.

Data analysis

Data capturing, coding and analysis procedures were the same as those described in Chapter 5.1. Dependent variables of soil bulk density, soil shear stress and soil moisture from the main data set were assigned respective independent variables. Class variables for each dependent variable were determined as required by the SAS system and analyses of variance (ANOVA) were carried out for the respective dependent variables. GLMs were used for the ANOVA tests. One way ANOVA, with plot as the independent variable, was run for each of the soil properties to determine how implement renovation influenced these parameters. In order to determine the changes in soil properties, the farmer, plot (A or B), depth (150 mm and 300 mm) and the month were the independent variables used in the GLM procedures. For yield and plant height determination, farmer and plot were the independent variables used in the models to compare the differences in soil physical characteristics in the plots ploughed before and after implement renovation.

5.2.5 Results

5.2.5.1 Soil physical characteristics

Four soil textural classes were identified in the various test plots as sandy, loamy sand, sandy loam, and sandy clay loam. Table 5.7 shows soil types mostly found in test plots at two depths and the mean reduction in percent sand at 150-300 mm depth compared to percent sand at 0-150 mm depth. Texture varied with depth in the majority of test plots. At 0-150 mm depth, soil textural classes and respective number of plots were as follows: loamy sand (42%), sand (28%), sandy loam (21%) and sandy clay loam (9%). At 150-300 mm depth, the number of plots and respective textures were loamy sand (46%), sandy loam (28%), sandy clay loam (14%) and sand (12%).

Table 5.7: Predominant soil textural classes in test plots in the different areas at 0-150 mm and 150-300 mm depth and reduction of % sand at 150-300 mm depth

Study area	Number of test sites	Predominant soil texture		Mean sand reduction at 150-300 mm depth (%)
		0-150 mm depth	150-300 mm depth	
Chedenje	6	sandy loam	Sandy clay loam	5
Gari	10	loamy sand	Sandy loam	8
Mshagashe	9	Sand	Loamy sand	4
Mushandike	4	Sand clay loam	Sandy clay loam	5
Mutangi	12	loamy sand	Loamy sand	5
Nyimai	12	Sand/loamy sand	Loamy sand/ sandy loam	6

Soil moisture content and shear stress monitored after ploughing varied with depth at which measurements were taken. However, depth was not significant (P=0.06) in predicting soil bulk density.

Figures 5.9 to 5.14 show how soil physical characteristics (bulk density, shear stress and moisture content) varied over a three-month period after ploughing in two different soil types, sandy and sandy clay loams, in Mshagashe and Chedenje respectively, in the 2000-2001 season. For each soil type the three soil properties were measured at each respective site. Measurements of soil properties at time=0 where taken on undisturbed soil on the test date just before ploughing.

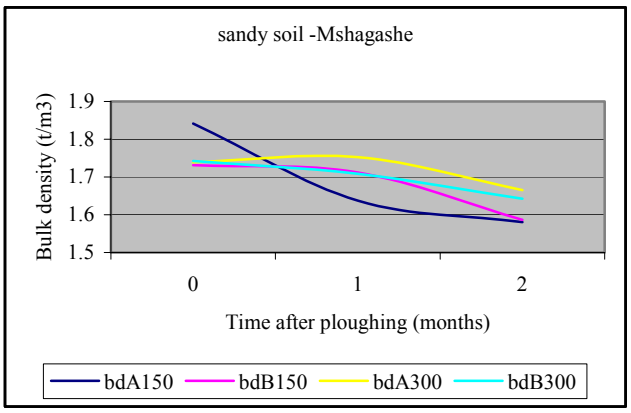

Figure 5.9: Variation in soil bulk density in sandy soil in Mshagashe at 150 mm and 300 mm depths
(bdA150=bulk density at 150 mm depth, bdB= bulk density at 150 mm depth
bdB= bulk density at 300 mm depth, bdB= bulk density at 300 mm depth)

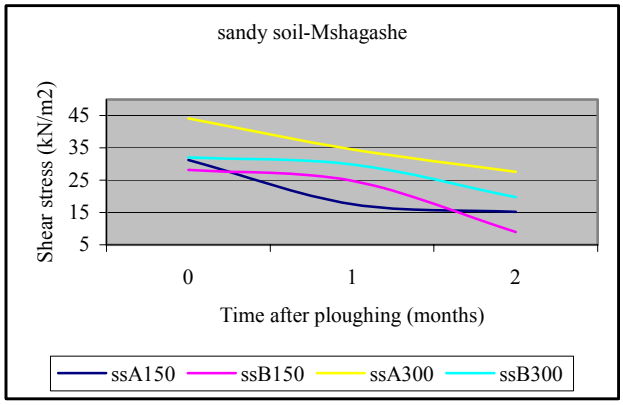

Figure 5.10: Variation in soil shear stress in sandy soil in Mshagashe at 150 mm and 300 mm depths
(ssA150= shear stress at 150 mm depth, ssB= shear stress at 150 mm depth
ssB= shear stress at 300 mm depth, ssB= shear stress at 300 mm depth)

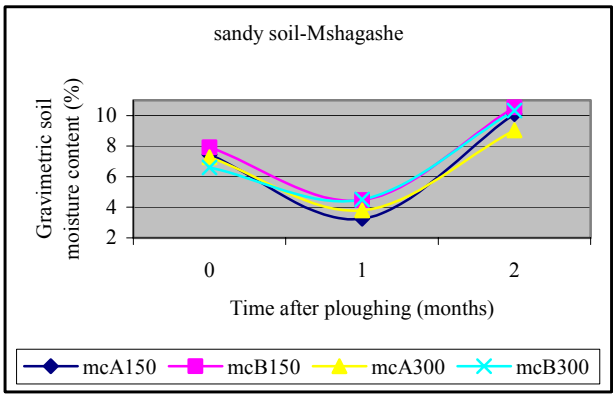

Figure 5.11: Variation in soil moisture content in sandy soil in Mshagashe at 150 mm and 300 mm depths
(mcA150= moisture content at 150 mm depth, mcB= moisture content at 150 mm depth
mcB= moisture content at 300 mm depth, mcB= moisture content at 300 mm depth)

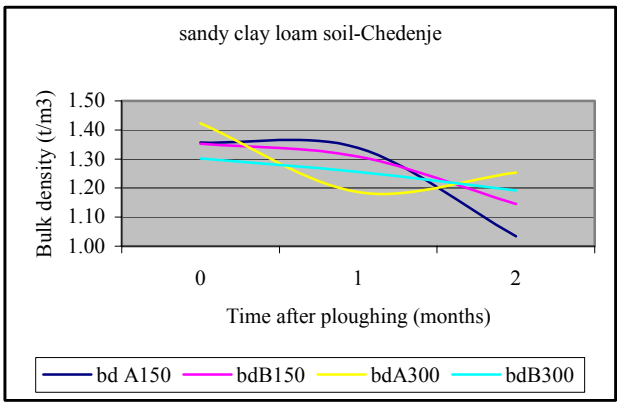

Figure 5.12: Variation in soil bulk density in sandy clay loam soil in Chedenje at 150 mm and 300 mm depths
(bdA150=bulk density at 150 mm depth, bdB= bulk density at 150 mm depth
bdB= bulk density at 300 mm depth, bdB= bulk density at 300 mm depth)

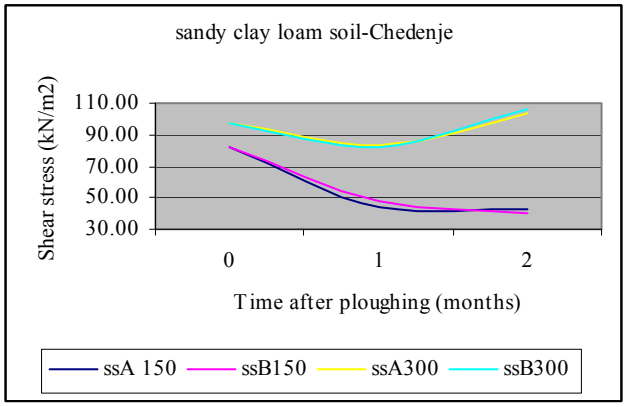

Figure 5.13: Variation in soil shear stress in sandy clay loam soil in Chedenje at 150 mm and 300 mm depths
(ssA150= shear stress at 150 mm depth, ssB= shear stress at 150 mm depth
ssB= shear stress at 300 mm depth, ssB= shear stress at 300 mm depth)

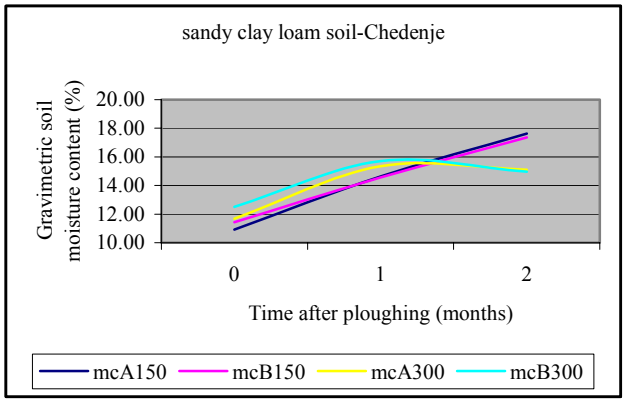

Figure 5.14: Variation in soil moisture content in sandy clay loam soil in Chedenje at 150 mm and 300 mm depths
(mcA150= moisture content at 150 mm depth, mcB= moisture content at 150 mm depth
mcB= moisture content at 300 mm depth, mcB= moisture content at 300 mm depth)

The plot, depth of sampling and month were significant ($P<0.0001$) in estimating soil bulk density, shear stress and moisture content. A one way ANOVA run with plot as the independent variable showed that moisture content varied significantly between paired plots ($P=0.0002$). There was no significant difference ($P=0.0912$) in bulk density as affected by implement renovation in the paired plots, neither was there significant difference in shear stress ($P=0.0532$). There was insignificant ($P=0.1840$) difference in bulk density at different depths in paired plots ploughed before and after plough renovation. Significant ($P=0.0001$ and $P=0.0269$) differences in shear stress and moisture content at different depths were observed in the paired plots, respectively.

5.2.5.2 Agronomic measurements

Crop performance was associated with implement renovation. Plant heights for maize and cotton measured in paired plots showed some difference at each site but the differences were not significant (P=0.3527 and P=0.1038) for maize and cotton crops, respectively. Tables 5.8 and 5.9 summarise some agronomic measurements for the two seasons.

Table 5.8: Agronomic results from trials

			Mean plant populations (10^3/ha)			Mean yields (t/ha)		
Season	**N**	**Crop**	**Plot A**	**Plot B**	**% increase**	**Plot A**	**Plot B**	**% increase**
1999-2000	11	**Maize**	30.4	31.3	3	1.1	0.99	-10
2000-2001	14		33.4	31.1	-6.9	1.83	2.27	24
1999-2000	4	**Cotton**	25.9	27.4	5.8	0.66	0.60	-9
2000-2001	4		30.6	29.4	-4	1.03	1.15	12

Table 5.9: Crop row spacing in trial plots

			Mean crop row spacing (cm)	
Season	**n**	**Crop**	**Plot A**	**Plot B**
1999-2000	11	**Maize**	83	81
2000-2001	14		77	79
1999-2000	4	**Cotton**	93	92
2000-2001	4		82	83

5.2.6 Discussion

Initial soil physical characteristics varied between sites due to different field conditions. Soil bulk density measured after ploughing showed that there was no significant difference in plots ploughed before and after renovation even though quality of tilth was better after renovation. Plough renovation resulted in lower soil shear strength and higher soil moisture content retention. Variations in bulk density, moisture content and shear stress between sites influenced the performance of implements, especially draught that increased as the percent clay increased from sandy to sandy clay loam, for example in Mshagashe and Mushandike, respectively.

Probably due to the small sample of farmers who were able to achieve reasonable yields, the increases in yield for both maize and cotton were not significantly different ($P>0.05$) before and after implement renovation. Adverse weather conditions experienced in both seasons could have had an effect on the results obtained. Results suggest that the increased ploughing depth achieved by the renovated plough disturbed the soil more than the unrenovated plough. Consequently this provided a good environment for crop growth because of better moisture infiltration and retention.

Weeding efficiency increased after plough renovation due to improved penetration resulting in better soil inversion and weed burial (Chapter 5.1). Improved weed burial meant that the hand-weeding burden would be reduced leaving fields with relatively less weeds and enabling a good environment for improved crop growth that would produce better yields.

The large variations in plant population for both maize and cotton indicated that households used different seeding rates per unit area. Placing seed on the furrow bottom using third furrow planting (TFP) in plot B, where the plough worked deeper than in plot A, gave germination problems and farmers had to gap-fill. This affected both plant population, crop stand and yields for the 1999-2000 season.

Row spacing for maize planted using TFP (farmers' practice) should theoretically be about 600 mm since this is determined by the width of cut. Ploughs with worn out shares would achieve smaller furrow slices and crop rows would be closely spaced. The mean row spacings achieved with TFP were more than 600 mm, suggesting that farmer-set ploughs ploughed wide and left unploughed portions of furrows as was observed during ploughing before renovation. Mechanical weeding may be difficult for the operator because of the need to frequently adjust width of work as rows made using TFP were rarely straight or evenly spaced.

Maize germination problems encountered could be overcome by ploughing deep soon after harvest followed by shallow ploughing, with the plough correctly adjusted and planting behind the plough in spring. Alternatively, planting furrows could be marked using a plough without the mouldboard or a ripper following deep ploughing in spring and then plant.

Results indicate that households used lower plant populations for both maize and cotton. The wide range of row spacing used for both crops showed that row spacings were rarely near recommended specifications. Plant populations were therefore low especially for maize which would result in low yields per area planted. However there is need to balance the soil fertility problems and erratic rainfall in these marginal areas with plant population since poorer farmers could not afford fertilisers and did not have adequate livestock from where they could obtain kraal manure. Lower plant populations could be used without compromising yields. It was also noted that the lower populations used gave higher yields particularly in plots ploughed after renovating ploughs. This may have been due to renovation of ploughs resulted in deeper ploughing and therefore provided a better environment for crop growth as well as the elimination of TFP by opening planting furrows after ploughing with renovated ploughs.

Renovation of implements can improve the standard of tillage and tilth that influences soil properties which encourage better growth resulting in improved yields. Plough renovation resulted in more soil disturbance due to deeper ploughing and improved soil moisture retention.

The hypotheses that implement renovation improves tillage and crop yields as well as reducing shear strength and improves soil moisture content can be accepted. Renovation did not significantly reduce soil bulk density.

5.2.7 Conclusion

Renovation of ploughs produced a better and uniform tilth without significantly reducing bulk density but reduced soil shear strength.

Reconditioning and correct setting of implements improved soil conditions resulting in better moisture retention and crop growth. Although results showed no significant differences in crop yield between plots ploughed before and after renovation, improved yields were recorded after renovation. Yields were also affected by other factors such as season quality and crop establishment.

Deep ploughing followed by opening furrows for maize and cotton planting at the start of the ploughing season seemed to be a good option for crop establishment and an alternative to the traditional third furrow planting of maize. It reduced the weeding burden and produced a good seedbed for improved plant growth. Farmers who prefer TFP for maize production can plough deeply soon after harvest and then shallow plough and plant behind the plough or rip in spring.