

**EXPLORING THE EFFECTIVENESS OF DIFFERENT FERTILIZER  
FORMULATIONS IN ALLEVIATING ZINC DEFICIENCY IN  
SMALLHOLDER MAIZE PRODUCTION SYSTEMS IN ZIMBABWE**

**By**

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the degree of**

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## DECLARATION

I, **Muneta Grace Manzeke**, do hereby declare that this thesis is a result of original research work undertaken by myself except where clearly and specifically acknowledged. It is being submitted for the partial fulfilment of the degree of Master of Philosophy in Agriculture. It has not been submitted before for any degree or examination in any other University.

Date \_\_\_\_\_

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## ABSTRACT

Fertilization of staple cereal crops in smallholder farming systems of sub-Saharan Africa has mostly focused on supply of nitrogen (N), phosphorus (P) and potassium (K), despite the widespread deficiencies of micronutrients that include zinc (Zn). Cereal crops grown on granitic sandy soils occurring widely in Southern Africa have poor Zn nutrition. This study focused on evaluating the potential of different soil fertility management regimes in enhancing maize (*Zea mays* L.) productivity, grain nutritional quality and nutrient uptake on nutrient-depleted soils on smallholder farms of Zimbabwe. A preliminary soil fertility survey and on-farm experiments were conducted in different agro-ecological regions (NR) in smallholder farming areas of Wedza (NR II: 750 - 800 mm yr<sup>-1</sup>) and Makoni (NR III: 650-750 mm yr<sup>-1</sup>) districts in eastern Zimbabwe. The survey was conducted during the 2008/09 season to evaluate the effect of farmers' soil fertility management practices on soil Zn status and maize grain nutrient concentrations. Ethylenediaminetetraacetic acid (EDTA) extractable soil Zn from the different farmers' fields ranged from 0.5 – 2.43 mg kg<sup>-1</sup> with the highest concentration associated with application of woodland leaf litter to maize. In both study areas, combined use of organic nutrient resources and inorganic fertilizers produced maize grain yields >2.1 t ha<sup>-1</sup>, sharply contrasting the non-fertilized treatment which yielded <0.8 t ha<sup>-1</sup>. Up to 46% and 64% increase in grain Zn concentration was measured against the control in Makoni and Wedza respectively. Co-application of inorganic fertilizers with cattle manure or leaf litter, and legume-cereal rotations significantly influenced Zn uptake (p<0.01), with uptake of up to 48.5 g Zn ha<sup>-1</sup> measured in Wedza. Maize grain from farmers' fields was characterized by low Zn concentrations and poor Zn bioavailability as indicated by exceptionally high phytic acid to Zn (PA:Zn) molar ratios of 150. The PA:Zn ratio is a widely used criterion to predict bioavailability of Zn in humans and should not exceed 15. Field experiments conducted between 2008 and 2011 evaluated the effect of different Zn fertilizer formulations on maize yields and subsequently grain Zn concentration. Results showed that application of basal and foliar Zn fertilizers, solely or in combinations increased maize grain yields, out yielding the non Zn treatment. Significant maize grain Zn uptake differences (p<0.01) among treatments were observed during the two seasons, with highest uptake of ~114 g Zn ha<sup>-1</sup> attained after application of a basal NPK fertilizer at 11 kg Zn ha<sup>-1</sup>. The Zn concentrations measured in maize grain during the 2008/09 and 2009/10 seasons ranged from 14.3 – 30.3 mg kg<sup>-1</sup> and 18.7 – 39.0 mg kg<sup>-1</sup> respectively, with the highest concentrations being realized after co-application of basal and foliar Zn fertilizers. There was a significant and positive linear relationship between EDTA- extractable soil Zn and maize grain Zn concentration (R<sup>2</sup>>0.80). An assessment of maize grain yield and quality benefits of Zn following application of organic nutrient resources and mineral fertilizers at different levels indicated that co-application of organic and inorganic fertilizers increased maize yields by 5.5-fold compared to the unfertilized treatment. Maize produced under leaf litter in combination with mineral NPK and Zn had the highest grain Zn concentration of up to 33.0 mg kg<sup>-1</sup>. Overall results indicated that mineral fertilizers as currently applied by farmers promote Zn mining and are likely to result in long-term severe deficiencies in soils. Integrated soil fertility management practices as currently presented to smallholder farmers are limited by lack of micronutrients which are required to improve available soil Zn, yields and nutritional quality of staple maize grains. While application of Zn- based fertilizers can be an entry point for enhancing grain quality of staple maize, farmers who apply sole mineral fertilizers have a higher demand for Zn than those who use combinations of organic nutrient resources and inorganic fertilizers.

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## **DEDICATION**

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## TABLE OF CONTENTS

<b>DECLARATION</b> .....	i
<b>ABSTRACT</b> .....	ii
<b>ACKNOWLEDGEMENTS</b> .....	iii
<b>DEDICATION</b> .....	iv
<b>TABLE OF CONTENTS</b> .....	v
<b>LIST OF TABLES</b> .....	xii
<b>LIST OF FIGURES</b> .....	xiv
<b>LIST OF APPENDICES</b> .....	xv
<b>LIST OF ACRONYMS AND ABBREVIATIONS</b> .....	xvi
<b>Chapter 1</b> .....	1
<b>Introduction and problem definition</b> .....	1
1.1 Background.....	1
1.2 Rationale .....	5
1.3 Area of study.....	7
1.4 Hypotheses.....	7
1.5 Objectives of the study.....	8
1.6 Thesis structure .....	8
<b>Chapter 2</b> .....	10
<b>Literature Review</b> .....	10
2.1 Smallholder farming system in Zimbabwe: Nutrient status of fields .....	10
2.2 Soil Zn status in Southern Africa and other parts of the world .....	11
2.3 Soil fertility management strategies for improved crop productivity .....	12
2.4 Fertilizer types and their importance .....	14
2.4.1 Mineral fertilizer use in smallholder farms .....	14
2.4.2 Organic fertilizer use .....	16
2.4.3 Foliar fertilizers .....	17

2. 5 Zinc importance to plants and symptoms associated with deficiency .....	19
2.6 Forms of Zn in soils .....	21
2.7 Factors affecting the total Zn content of soils and availability to plants .....	22
2.7.1 Hydrogen – hydroxide ion concentration in soil (pH).....	22
2.7.2 Phosphorus .....	23
2.7.3 Organic matter .....	25
2.7.4 Soil type and clay content .....	26
2.7.5 Interaction of Zn with other nutrients.....	27
2.8 Zinc nutrition in smallholder communities.....	28
2.9 Efforts to correct micronutrient deficiencies in food crops and humans.....	29
2.9.1 Supplementation.....	29
2.9.2 Food diversification.....	30
2.9.3 Industrial fortification.....	31
2. 9.4 Biofortification .....	31
2.10 Measurement of bioavailability of Zn in human diets.....	32
2.11 Research on zinc in Zimbabwe .....	33
<b>Chapter 3 .....</b>	<b>35</b>
<b>General Materials and Methods .....</b>	<b>35</b>
3.1 Study sites .....	35
3.2 Main approaches used.....	37
3.3 Soil analyses.....	38
3.3.1 Determination of soil texture.....	38
3.3.2 pH .....	39
3.3.3 Total N determination .....	39
3.3.4 Total P determination .....	40
3.3.5 Available P analysis .....	40
3.3.6 Organic carbon determination .....	41

3.3.7 Exchangeable bases .....	42
3.3.8 Determination of available zinc.....	42
3.4 Plant tissue analyses.....	43
3.4.1 Determination of plant nitrogen .....	43
3.4.2 Determination of plant phosphorus .....	44
3.4.3 Extraction and determination of Ca, Mg, K, S, Zn .....	44
3.4.4 Determination of maize grain nutrient concentration and uptake patterns.....	45
3.4.5 Determination of phytic acid in grain.....	46
<b>Chapter 4 .....</b>	<b>47</b>
<b>Soil fertility management practices, soil Zinc status and maize grain nutritional value on smallholder farms in Eastern Zimbabwe .....</b>	<b>47</b>
4.1 Abstract.....	47
4.2 Introduction.....	48
4.3 Materials and methods .....	51
4.3.1 Identification and characterization of farmers' common soil fertility management practices .....	51
4.3.2 Assessment of soil zinc status as influenced by soil fertility management practices.....	53
4.3.3 Soil sampling and laboratory analysis.....	54
4.3.4 Organic nutrient resources sampling and laboratory analysis.....	54
4.3.5 Determination of maize yield performance and Zn uptake patterns .....	56
4.4 Statistical analyses .....	57
4.5 Results.....	57
4.5.1 Distribution of soil fertility management practices among farmers.....	57
4.5.2 Nutritional composition of organic resources accessible to farmers.....	59
4.5.3 Effect of farmers' soil fertility management practices on soil Zn status.....	59
4.5.4 Soil fertility management effects on maize grain yield.....	60
4.5.5 Soil fertility management effects on grain Zn concentration and uptake.....	61
4.5.6 Effect of soil fertility management domains on indicators of Zn bioavailability...65	



4.6 Discussion.....	67
4.6.1 Nutrient resources and soil fertility management practices commonly used by farmers.....	67
4.6.2 Influence of organic nutrient resources on soil Zn, P and Ca status .....	68
4.6.3 Maize grain yield under different soil fertility management practices.....	70
4.6.4 Effect of soil fertility management practice on maize grain nutrient concentration and Zn uptake .....	71
4.6.5 Maize grain indicators of Zn bioavailability as affected by fertility differences ...	73
4.7 Conclusions.....	74
<b>Chapter 5 .....</b>	<b>76</b>
<b>Effects of different zinc fertilizer formulations and methods of application on maize productivity and grain quality.....</b>	<b>76</b>
5.1 Abstract.....	76
5.2 Introduction.....	76
5.3 Materials and methods .....	79
5.3.1 Selection and establishment of field sites.....	79
5.3.2 Fertilizer treatments and crop planting.....	79
5.3.3 Agronomic management of field experiments .....	81
5.3.4 Plant sampling and analysis for Zn uptake.....	81
5.3.5 Foliar fertilizer application and grain sampling .....	82
5.3.6 Assessment of Zn residual effects .....	82
5.4 Statistical analyses .....	83
5.5 Results.....	84
5.5.1 Initial characterization of farmers` fields .....	84
5.5.2 Influence of different zinc fertilizers on maize grain yield .....	85
5.5.3 Contribution of different Zn fertilizers to maize ear leaf N, P and Zn concentrations.....	87
5.5.4 Effect of residual fertility on ear leaf Zn and P .....	88

5.5.5 Ear leaf aluminum and iron concentrations as affected by application of Zn-based fertilizers.....	89
5.5.6 Influence of basal and foliar fertilization on maize grain Zn enrichment.....	91
5.5.7 Maize grain Zn uptake and relationship between ear-leaf and grain Zn concentration.....	92
5.5.8 Effect of different Zn- based fertilizer formulations on grain N, P and Ca concentration.....	94
5.5.9 Influence of different fertilizers on phytic acid and calcium and their interaction with zinc.....	95
5.5.10 Assessment of Zn fertilization and residual fertility on plant available soil Zn.....	100
5.5.11 Relationship between plant available soil Zn and grain Zn as affected by application of different Zn- based fertilizer formulations.....	101
5.6 Discussions.....	102
5.6.1 Influence of Zn- based fertilizer formulations on maize grain yields.....	102
5.6.2 Ear-leaf nutrient concentrations under different Zn fertilizer formulations.....	103
5.6.3 Influence of different fertilizer formulations on maize grain Zn concentrations and uptake.....	104
5.6.4 Indicators of Zn bioavailability as affected by different Zn- based fertilizer formulations.....	106
5.6.5 Relative contribution of Zn fertilizers to build up of available soil Zn.....	107
5.7 Conclusions.....	108
<b>Chapter 6.....</b>	<b>109</b>
<b>Interactions of zinc with organic and inorganic fertilizers: Implication on improving crop productivity and grain nutrient concentration.....</b>	<b>109</b>
6.1 Abstract.....	109
6.2 Introduction.....	110
6.3 Materials and methods.....	112
6.3.1 Site selection.....	112
6.3.2 Experimental treatments.....	113
6.3.3 Determination of nutrient composition of organic nutrient resources.....	114

6.3.4 Planting and agronomic management of field site .....	114
6.3.5 Maize grain and soil sample collection .....	114
6.3.6 Grain and soil sample preparation and laboratory analysis.....	115
6.4 Statistical analyses .....	116
6.5 Results.....	116
6.5.1 Characteristics of the study site.....	116
6.5.2 General physico-chemical characteristics of organic nutrient sources applied....	117
6.5.3 Effect of Zn application on maize grain yield under organic and inorganic fertilizer management.....	118
6.5.4 Inorganic NPK, Zn and organic fertilizer effects on maize grain Zn concentration .....	120
6.5.5 Grain Zn uptake as affected by inorganic NPK, Zn and organic fertilizer application .....	122
6.5.6 Zinc, inorganic NPK and organic fertilizer effects on grain P concentration and uptake .....	123
6.5.7 Plant available soil Zn and P as influenced by Zn application under organic and inorganic fertilizer management.....	125
6.6 Discussion.....	128
6.6.1 Maize grain yield under Zn application and organic and inorganic fertilizer management.....	128
6.6.2 Influence of Zn application and organic and inorganic fertilizers on maize grain nutrient concentration and uptake .....	129
6.6.3 Influence of Zn application and organic nutrient resources on plant available soil Zn and P status.....	131
6.7 Conclusions.....	132
<b>Chapter 7 .....</b>	<b>134</b>
<b>Overall discussion, conclusions and recommendations.....</b>	<b>134</b>
7.1 Micronutrients and their role in plant nutrition.....	134
7.2 Problem of low zinc stocks in Zimbabwe.....	135
7.3 Influence of farmer soil fertility management on zinc status and distribution .....	136

7.4 External Zn application as a critical factor for improved grain quality.....	137
7.5 Use of organic and inorganic fertilizer combinations for improved grain yields and quality .....	138
7.6 Implications of current fertilizer policies on micronutrient management in Zimbabwe ..	139
<b>References</b> .....	141
<b>APPENDICES</b> .....	171
Appendix 1 List of publications from this thesis .....	171
Appendix 2 The participatory rural appraisal checklist used in Wedza and Makoni Communal Areas, Zimbabwe .....	172

## LIST OF TABLES

Table 3.1 Values used to interpret adequacy of nutrients in different fields, using nutrient concentration values in maize shoots at 4 weeks after emergence.....	45
Table 3.2 Values used to interpret adequacy of Zn in maize ear leaf samples .....	45
Table 4.1 Common soil fertility management practices as recognised by smallholder farmers in Wedza and Makoni districts of Zimbabwe .....	53
Table 4.2 Zinc concentration and general chemical characteristics of organic nutrient sources collected from different management domains in smallholder farms in eastern Zimbabwe.....	59
Table 4.3 Effect of different management practices on soil chemical properties in Wedza and Makoni.....	61
Table 4.4 Zinc, Ca and P concentration in maize grain and Zn uptake as influenced by farmer management practices in Wedza and Makoni smallholder farming areas in Zimbabwe.....	64
Table 4.5 Effect of fertility treatments on indicators of Zn bioavailability: PA, PA: Zn and Ca x PA: Zn.....	66
Table 5.1 Treatments used to evaluate the effect of different Zn fertilizer formulations on maize productivity and maize yielding components. ....	80
Table 5.2 Composition of different fertilizers used to investigate effect of Zn on maize productivity and nutritional quality.....	81
Table 5.3 Physical and chemical characteristics of soils collected from two field sites on which the Zn trials were established in Zimbabwe .....	84
Table 5.4 Maize ear leaf N, P and Zn concentration as affected by different fertilizers in Wedza, Zimbabwe during the 2008/09 cropping season .....	88
Table 5.5 Effect of different Zn fertilizer treatments on leaf P and Zn concentration of maize grown under smallholder farmer management in Wedza and Makoni districts, Zimbabwe.....	90
Table 5.6 Maize grain Zn concentrations as affected by different foliar and basal fertilizer formulations applied on smallholder farms in Zimbabwe.....	91
Table 5.7 Effect of basal and foliar Zn fertilizers on grain N, P and Ca concentrations of maize grown in Wedza and Makoni smallholder farming areas .....	96
Table 5.8 Effect of Zn fertilization on PA, PA: Zn and Ca x PA: Zn molar ratios in Wedza and Makoni smallholder farming areas in Zimbabwe.....	98

Table 5.9 Assessment of residual Zn effects and foliar Zn fertilizer application on PA, PA: Zn and Ca x PA: Zn molar ratios in Wedza and Makoni maize production systems, Zimbabwe .....	99
Table 6.1 Treatments structure to investigate the influence of N, P and Zn application, in combination with organic nutrient resources, on maize productivity and nutrient uptake .....	113
Table 6. 2 Physical and chemical characteristics of the soil at site on which the nutrient omission experiment was established.....	117
Table 6. 3 Nutrient compositions of organic amendments applied to selected treatments.....	118
Table 6. 4 Zinc concentration and uptake in maize grain after application of Zn under organic and inorganic fertilizer management in Wedza, eastern Zimbabwe .....	122
Table 6.5 Added grain yield and Zn uptake benefits following fertilization with Zn in combination with macronutrients and organic nutrient resources.....	123
Table 6.6 Grain P concentration and uptake following fertilization with macronutrient and Zn fertilizers in combination with organic nutrient resources in Wedza .....	124
Table 6.7 Soil chemical properties measured during the 2009/10 cropping season after 1 <sup>st</sup> application of organic and inorganic fertilizer combinations.....	127

## LIST OF FIGURES

Figure 3.1 An illustration of Wedza and Makoni districts of Eastern Zimbabwe where on-farm maize trials were conducted .....	36
Figure 4.1 Selected farmers' fields distribution in Goto Ward, Wedza district .....	53
Figure 4.2 Selected farmers' fields distribution in Nyahava Ward, Makoni District .....	56
Figure 5.1 Rainfall received during the 2008/09 and 2009/10 cropping seasons in Wedza and Makoni.....	83
Figure 5.2 Maize grain yields obtained during the 2008/09 season after application of different zinc containing fertilizers. ....	86
Figure 5.3 Maize grain yields obtained in the second season of 2009/10 following residual basal fertility and application of foliar Zn fertilizers. ....	87
Figure 5.4 Maize grain Zn uptake measured after application of different Zn fertilizers during the 2008/09 season in Wedza and Makoni.....	93
Figure 5.5 Relationship between ear-leaf and grain Zn concentrations in Wedza and Makoni	94
Figure 6.1 Total rainfall measured in Wedza, eastern Zimbabwe during the 2010/11 cropping season .....	115
Figure 6.2 Maize grain yields after application of Zn in combination with organic and inorganic fertilizers in Wedza, eastern Zimbabwe in the 2009/10 season .....	119
Figure 6.3 Residual organic and Zn fertility effects on maize grain yields following application of inorganic NPK in the 2010/11 season in Wedza, Zimbabwe.....	121

## **LIST OF APPENDICES**

Appendix 1 List of publications and award from this thesis .....	171
Appendix 2 The participatory rural appraisal checklist used in Wedza and Makoni Communal Areas, Zimbabwe.....	172



## LIST OF ACRONYMS AND ABBREVIATIONS

AAS	atomic absorption spectrophotometer
AEW	Agriculture Extension Worker
AN	ammonium nitrate
C: N	carbon to nitrogen ratio
DTPA	diethylenetriaminepentaacetic acid
DW	dry weight
EDTA	ethylenediaminetetraacetic acid
ISFM	Integrated Soil Fertility Management
M	molarity
MDG	Millennium Development Goal
N	nitrogen
NGO	Non Governmental Organization
NR	Natural Region
OC	organic carbon
P	phosphorus
ppm	parts per million, synonymous to mg/kg
PA: Zn	phytic acid to zinc molar ratio
SOFECSA	Soil Fertility Consortium for Southern Africa
SOM	soil organic matter
UNICEF	United Nations Children's Fund
UV	ultra violet
WAE	weeks after emergence
Zn	zinc

# Chapter 1

## Introduction and problem definition

### 1.1 Background

Maize is a staple crop and source of calories in the diets of developing country populations, ranking third after rice and wheat (FAOSTAT, 2010). Cheaper than either rice or wheat, maize is important for more than 900 million low income consumers who live in African, Asian, and Latin American countries. Unfortunately, the over-dependence of millions of poor people on maize results in poor health, stunted growth, reduced capacity for physical activity, and in extreme cases, high incidence of nutritional deficiency diseases such as kwashiorkor, anemia, and corneal blindness (CIMMYT, 2011). In Zimbabwe, maize is the country's staple cereal and is mainly a source of energy, providing up to 30% of total calories in human diets (FAOSTAT, 2006).

Although the proportion of land allocated to food crops in Zimbabwe is dependent on the agro-ecological zone (AEZ), availability or size of land and farm productivity, maize is the dominant crop across all AEZ and occupies 50 – 70% of the cropped areas in natural regions (NR) I and II, and 40 – 50% in NR III, IV and V (Ashworth, 1990; AGRITEX, 1994). The dominance of maize over the small grains (pearl millet and sorghum), which only occupy 10-25% of cropped area, is a reflection of its importance for subsistence and as a cash crop in smallholder communal areas. As a result of this, maize accounts for 49% of the fertilizers used in the country's farming sector (Mashingaidze, 2004; FAO, 2006).

The three main farming systems in Zimbabwe include smallholder farms (communal area, old resettlement and A1-model households), medium scale farms (old small-scale commercial and A2-model farms) and large scale commercial farms, conservancies and estates (Chenje et al., 1998; Rukuni, 1994; Scoones et al., 2010). The communal and resettlement smallholder farming system is characterized by a labour intensive production system with the exception of resource endowed farmers who are able to use ox-drawn implements during production. Rainfall is the main determinant of maize production patterns in smallholder communal farming in Zimbabwe. Low rainfall and severe dry spells within the rainy season compromise crop yields. Inherent deficiencies in nitrogen (N), phosphorus (P) and sulphur (S) have been observed on granite derived sandy soils on communal farms in Zimbabwe (Mashingwani, 1983) and are also known to limit crop productivity. These granite derived sandy soils are broadly classified as lixisols (World Reference Base, 1998). Lack of agricultural inputs and over-exploitation of soils through mono-cropping with little nutrient inputs exacerbate nutrient deficiencies in these soils.

While crop production in smallholder farming systems has been dominated by maize monoculture, legume-cereal rotations and their benefits of substantial build-up of soil fertility and provision of additional source of food for improved human nutrition have been on the increase in the past years (Snapp et al., 1999; Kanonge et al., 2009; Svubure et al., 2010). Application of organic nutrient resources such as cattle manure, woodland litter, compost, green manure and grain legumes are several options available to farmers for amelioration of soil fertility (Mapfumo, 2006) and improved crop yields.

Apart from use of locally available nutrient resources, farmers in sub-Saharan Africa apply NPK containing fertilizers in the hope of achieving high yields. However, yields remain as low as  $<1 \text{ t ha}^{-1}$  (Abunyewa and Mercer-Quarshie, 2004; Mafongoya et. al., 2006) implying other factors which include inadequacies of soil nutrients such as zinc (Zn) and poor farmer management practices might be limiting maize productivity. Earlier work done in Murewa in Zimbabwe showed that continuous application of ammonium nitrate (AN) and single super phosphate (SSP) fertilizers still gave low maize yields (Masvaya, 2007). Zinc deficiency is common in sub-Saharan Africa, including Zimbabwe and other parts of the world (Grant, 1981; Alloway, 2004). Current inorganic fertilizers commonly used in Zimbabwe for maize production such as basal Compound D (7% N: 14%  $\text{P}_2\text{O}_5$ : 7%  $\text{K}_2\text{O}$ : 6.5% S) produced by the Zimbabwe fertilizer Company (ZFC) and top dressing AN with 34.5% N, do not contain Zn. Continuous application of these fertilizers may lead to depletion as Zn which is taken up by plants is not replenished (Nyathi and Campbell, 1993). In Zimbabwe, compound Z (7% N, 14%  $\text{P}_2\text{O}_5$ , 7%  $\text{K}_2\text{O}$ , 6.5% S and 1% Zn) has been formulated to alleviate Zn imbalances in the soil but the high cost attached to production of this fertilizer led to little uptake and use by farmers. Fertilizer shortages and price increases have a negative impact on fertilizer use by smallholder farmers who often fail to buy fertilizers due to lack of financial resources.

Zinc is required for the normal growth of plants and has soil concentrations ranging from 10 – 300  $\text{mg kg}^{-1}$ ; with the least concentrations being measured in granite derived sandy soils (Alloway, 2004). Work carried out in Zimbabwe by Tagwira et al. (1993) also showed that soils derived from granitic parent material were inherently susceptible to Zn and copper (Cu) depletion, particularly under intensive and continuous cropping hence crop productivity is bound to be limited. Staple maize-based diets tend to be deficient in the essential

micronutrients such as Zn, among others, due to the nutritional composition of parent rock responsible for soil formation. Apart from inadequate intakes of Zn in cereal-based diets, human Zn malnutrition is also exacerbated by high levels of anti-nutritional compounds such as tannins, fibre, heavy metals and phytate (phytic acid-PA), which is the major component. The problem of Zn deficiency in soils further negatively impacts on maize productivity since maize roots have been known not to release mugineic acid (MA) which chelate Zn in the rhizosphere (Cakmak et al., 1998). However, not much data is available on cultivar differences in extraction of MA.

High grain Zn content ranging between 40 – 60 mg kg<sup>-1</sup> is required in cereal based human diets. The recommended intake of dietary Zn by children and adults range from 1.1 – 11.2 mg day<sup>-1</sup> and 3.0 – 19.0 mg day<sup>-1</sup>, respectively (FAO/WHO, 2002; Imtiaz et al., 2010). Regrettably, in poor communities, macro- and micronutrients food intakes are often inadequate resulting in Zn deficiency (Nube and Voortman, 2006). About two-thirds of all global deaths in children are associated with micronutrient nutritional deficiencies. Pregnancy complications, impaired brain development, sub-optimal growth and mortality are some of the severe symptoms associated with Zn deficiency (Welch, 2002a).

Zinc availability in the soil is affected by several factors which include the inherent fertility of the soil, removal of crop residues after harvest, crop type and poor farmer soil fertility management practices among other factors (Alloway, 2004). It has been found that 2.5 g Zn is mined for every tonne of maize stover removed (Archer, 1988). Application of organic nutrient resources such as cattle manure with an average of 22 mg Zn kg<sup>-1</sup> may contribute significantly to soil Zn status though concentrations may vary depending on the nutritional

value of grazing lands (Zingore, 2006). Some crop varieties produce a Zn-rich crop in soils low in Zn through efficient extraction of the nutrient from the soil. As food quality depends on the nutrient status of the soil on which it is grown (Nube and Voortman, 2006) it is important to improve the soil Zn nutrient status on smallholder farms.

This study intended to build on earlier research conducted by several authors on Zn (Madziva, 1981; Tagwira, 1991; Zingore, 2006) through comparison of effects of different Zn containing fertilizers in smallholder communities of Zimbabwe so as to improve maize grain quality. Improved understanding of the influence of farmer management of organic nutrient resources and mineral fertilizers on soil Zn status at farm level is required.

## **1.2 Rationale**

Little attention has been given to using micronutrient fertilizers to correct nutrient imbalances (Mukurimbira and Nemasasi, 1997) such that human micronutrient deficiencies are bound to occur. More than 300 enzymes involved in key metabolic processes in humans contain Zn (FAO/WHO, 1996) implying that food intake is supposed to be adequate in Zn. The International Zinc Nutrition Consultative Group (IZiNCG) estimated that about one third of the world's population was at risk from inadequate Zn intake. Cereal based diets are the major source of nutrients for the majority of the world's population. Unfortunately Zn concentrations in staple cereals have been reported to be as low as 20 mg kg<sup>-1</sup> (Rengel et al., 1999). Genetic biofortification has been reported to improve grain Zn concentration; however this strategy requires long-term crossing and back crossing. It is therefore important to improve the Zn content in the cereal grains through use of short-term strategies such as use of Zn-containing fertilizers (Nube and Voortman, 2006).

Meat is known to contain the highest concentrations of Zn ranging from 25 – 50 mg Zn kg<sup>-1</sup> (FAO/WHO, 1996) and has low concentrations of anti-nutritional compounds which include PA. Unfortunately, this significant source of Zn in the diet of many people is not available to improve Zn nutrition due to lack of farm animals. Aiming for consumption of foods whose nutritional quality has been improved through agricultural means remains the widely acceptable approach in ameliorating human Zn deficiencies, since dietary Zn supplementation programs may result in adverse health effects (Nube and Voortman, 2006).

In plants, Zn is required for carbohydrate metabolism, protein metabolism, membrane integrity, auxin metabolism and reproduction (Alloway, 2004). Symptoms associated with deficiency in plants include inter-veinal chlorosis, necrotic spots on leaves, rosetting of leaves and stunting of plants due to disturbances in metabolism of auxins, especially indole-acetic acid (IAA), which is a growth hormone (Alloway, 2008). Application of micronutrients to crops in combination with traditional fertilizers (N, P, K) was found to help break the cycle of low yields, poverty and poor human nutrition in SSA (Nube and Voortman, 2006). This implies that Zn fertilization is a promising approach for addressing deficiency in agriculture and human nutrition as well as improving the nitrogen fertilizer use efficiency for maize (Wendt et al., 1994). There may be need to blend existing fertilizers with micronutrients, especially Zn which is the main micronutrient known to be deficient in smallholder farming systems in Zimbabwe.

Most studies carried out in Zimbabwe concentrated on the fertility benefits of organic resources in terms of soil physical, chemical and biological properties, but with little attention to Zn nutrition. Of the studies carried out in Zimbabwe on Zn dynamics, more attention has

been given to application of basal Zn fertilizers than foliar Zn fertilizers to improve maize yields (Tagwira, 1991; Zingore, 2006). Application of foliar fertilizers was once carried out by Mupawose (1984), and a marked response of rice to Zn application was found on basalt derived soils in communal areas of Chisumbanje. Little research has been done on Zn foliar application in maize, which is the most widespread cereal grown in Zimbabwe's smallholder farming systems. Foliar sprays are important in making nutrients available to plants where adverse soil conditions might affect availability of nutrients as well as improving grain quality. Maize has a relatively high sensitivity to Zn deficiency with respect to yields, and thus puts the smallholder population at risk of Zn deficiency in their diet (ILZRO, 1975; Martens and Westerman, 1991). Considering that smallholder farmers grow high yielding hybrid seeds which remove large quantities of nutrients (Tagwira et. al., 1993), there is a need to replenish soil Zn with external fertilization.

### **1.3 Area of study**

This study aimed at improving maize productivity and grain quality to enhance human Zn nutrition through using different fertilizer formulations developed and/ or promoted under the Harvest Plus Zinc Initiative. Farmer management of different organic and inorganic fertilizers were also assessed to determine their influence on soil Zn status at field scale.

### **1.4 Hypotheses**

The study had the following hypotheses:

1. Use of different nutrient resources for soil fertility management by farmers has a differential influence on soil Zn status.



2. Application of Zn in basal or foliar fertilizer formulations has a differential influence on concentration of the nutrient in whole biomass versus grain.
3. Application of N, P and Zn in combination with cattle manure and/ or woodland litter significantly increases the soil Zn status and maize uptake of applied Zn.

### **1.5 Objectives of the study**

The overall objective of the study was to increase maize productivity and grain quality for improved human nutrition through application of different Zn fertilizer formulations on otherwise inherently Zn deficient soils on smallholder farms. The specific objectives of the study were to:

1. Evaluate the effect of different soil fertility management practices by smallholder farmers on soil Zn status and maize grain concentration.
2. Determine the effectiveness of different Zn fertilizer formulations on improving maize Zn uptake and grain productivity.
3. Determine the efficacy of basal- and foliar- applied Zn fertilizers in enhancing Zn concentration in maize grain.
4. Evaluate the added benefits of Zn fertilizer on maize yield and grain quality when co-applied with either cattle manure or woodland litter and different rates of N, P, K fertilizers.

### **1.6 Thesis structure**

Chapter 1 provides an introduction stating the problem statement and rationale of study. Detailed literature review on status of Zn in smallholder farming systems and options

available to ameliorate deficiencies are given in Chapter 2. A description of study sites and general materials and methods used in the study are given in Chapter 3. Chapter 4 discusses availability of Zn in soils under diverse farmer management systems in smallholder communities. Effects of different Zn fertilizers on improving available soil Zn concentration, maize productivity and maize grain quality is discussed in Chapter 5. Chapter 6 focuses on effectiveness of organic and inorganic fertilizer combinations on soil Zn status, maize productivity and grain quality. In Chapter 7, overall findings are discussed and conclusions drawn with recommendations and possible areas for future research proposed.

## **Chapter 2**

### **Literature Review**

#### **2.1 Smallholder farming system in Zimbabwe: Nutrient status of fields**

A system can be defined conceptually as any set of elements in an environment that are interrelated and interact among themselves (Hildebrand, 1986). Smallholder farming systems are characterized by complex interactions between the household, livestock, natural vegetation and cropping fields. Sub-systems such as marketing of horticultural produce, surplus maize and indigenous fruits also exist. Cattle ownership is the dominant indicator of wealth and cattle have a valuable input in soil fertility maintenance through recycling of nutrients from crop residues and transfer nutrients from rangelands (Bationo, 2004).

Smallholder farms in Zimbabwe are typically less than 5 ha (average 2 ha) (Ncube, 2007) though sizes vary with agro ecology. Smallholder farmers have permanent arable fields, close to communal grazing areas. Most farmers cultivate crops continuously on the same plots with little additions of nutrient resources, and this has led to severe decline in soil fertility (Zingore, 2006; Tittonel et. al., 2007). The smallholder farming system is somewhat closed with limited manipulation of the environment and is characterized by low external inputs, low risk, low output, simple technology and high labour use (Chivinge, 2004).

Deficiencies of N, P and S have been observed in sandy soils of Zimbabwe and at advanced stages of soil fertility depletion, deficiencies of magnesium (Mg), calcium (Ca) and micronutrients such as Zn and Cu also occur (Grant, 1981; Mugwira and Nyamangara, 1998).

More than 60% of these soils are planted to continuous maize, with small additions of nutrient resources and removal of crop residues to feed livestock (Mukurumbira and Nemasasi, 1997).

Although combined use of mineral and organic nutrient resources have positive effects of improved resource use efficiency which result in improved soil fertility and crop production, (Mtambanengwe and Mapfumo, 2006; Zingore, 2006), this soil fertility management practice is rarely used by smallholder farmers as mineral fertilizers are scarce and expensive. Consequently, macro- and micronutrients are not replenished to the degree that they are removed through crop harvesting hence depletion of important nutrients from the soil occurs. Current soil fertility levels in smallholder areas in Zimbabwe are low and declining and the fertility management practices used by most farmers are inadequate (Ahmed et. al, 1997; Mapfumo and Giller 2001).

## **2.2 Soil Zn status in Southern Africa and other parts of the world**

Agricultural soils with low Zn deficiency are widespread in the world (Alloway, 2008). During the 1950s, 1960s and 1970s, S, Mg and (less commonly) Zn and boron (B) deficiencies were detected in maize on sandy soils in Zimbabwe (Grant, 1981; Meterlerkamp, 1988). On the sandy loam and clay loam soils of Malawi, which are chronically deficient in macronutrients, micronutrients such as Zn and B were reported to be limiting at many sites (Wendt et al., 1994). Zambia and Mozambique have large areas of acidic soils with high levels of exchangeable aluminium ( $Al^{3+}$ ). However, there is no known antagonism or synergy relationship between Al and Zn. Additions of micronutrients to soil can improve the yield response to N and P on deficient soils. Zinc, B, S and Mg can often be included in existing fertilizer blends, when targeted to deficient soils since these nutrients can dramatically

improve fertilizer use efficiency and crop profitability. However, this normally attracts an extra cost compared to production of standard NPK fertilizers. Enhanced yields were obtained by including selected micronutrients in fertilizer blends (Grant, 1981). Experiences in Malawi provide a striking example of how fertilizer efficiency for maize can be raised by providing appropriate micronutrients on a location specific basis. Supplementation by S, Zn, B and K increased maize grain yields by 40% over the standard N and P recommendation alone (Wendt et al., 1994).

Reports have revealed that 30-50% of soils in the world exhibit Zn deficiency to different extents (Cakmak et al., 1999; Alloway, 2008; Cakmak, 2008) and more than two billion people cannot be supplied with sufficient Zn. Evidence has shown that Zn deficiency prevalence in humans is 13-17% of the population in sub-Saharan Africa, 18-39% in Asia (Bouis et al., 2011). The problem of Zn deficiency was reported to be serious in China where more than one-third of the agricultural land has been classified as deficient (Gao et al., 2005) with diethylenetriaminepentaacetic acid (DTPA) extractable soil Zn of  $<0.5 \text{ mg kg}^{-1}$ . In some parts of India, increasing deficiency of micronutrients, mainly Zn, has emerged as one of the major constraints in improving crop yields. Observed Zn- related human health problems in these areas have been associated with a low Zn availability in soils (Singh, 2009).

### **2.3 Soil fertility management strategies for improved crop productivity**

The choice of soil fertility management strategies by farmers is affected by the amount of nutrient resources available, labour requirements and the availability of land and draught power. Intensity of use of nutrient resources differs on different farms, as farmers have different access to resources. Smallholder farmers mainly depend on organic nutrient

resources to sustain crop productivity (Mapfumo and Giller, 2001; Mtambanengwe and Mapfumo, 2005) as they use little inorganic fertilizers. The impact of organic nutrient resources is often low due to inadequate amounts available and poor quality of the organic materials (Murwira and Palm, 1998). Cattle manure is the main organic nutrient resource used by farmers. Methods of handling and storage often result in loss of large amounts of some of the nutrients, N in particular, before the time of application (Mugwira and Murwira, 1997) through leaching and volatilization.

Woodland litter (leaf litter) is the other option for improving soil fertility but its use has been compromised by excessive deforestation of woodlands and forests (Campbell et al, 1998). Leaf litter improves soil structure and fertility and also rehabilitates degraded or compacted soils. Termitaria soil and ash are other sources of nutrients used by smallholder farmers to improve soil fertility, especially the resource constrained farmers in Zimbabwe (Mugwira and Murwira, 1997; Mtambanengwe and Mapfumo, 2008). When applied on sandy soils, termitaria soil improves structure of soils, increases yield especially of groundnuts, increase soil pH, improves water holding capacity thus reducing leaching and has long residual effects (Huchu and Sithole, 1994; Scoones, 2001). A study by Patterson et al. (2004) showed that ash can increase soil pH and supplement plant growth by adding minerals and macro- and micronutrients in acidic sandy soils when used as an amendment. Crop rotations maintain and improve soil fertility as well as minimize the carryover of pests and diseases to succeeding crops. Benefits of crop rotations involving grain, green manure and indigenous legumes such *Crotalaria pallida* (L.) over a continuous maize (*Zea mays* L.) cropping systems have been shown in Zimbabwe (Mupangwa et al., 2003; Matokwe, 2005, Nezomba et al., 2008) indicating that legumes are important for fixation of N which will benefit the succeeding crop.

Fertilizer use has been responsible for a large part of sustained crop productivity worldwide (Sanchez et al., 1997). Fertilizers have been shown to produce variable crop yield responses under smallholder farming conditions across locations and between fields. Although some NPKS fertilizers containing micronutrients such as Zn and B are manufactured in Zimbabwe, they are targeted for high value crops such as cotton (*Gossypium hirsutum* L.) and tend to be more expensive than standard NPKS fertilizer compounds. Maize fertilizers mainly used in Zimbabwe for supply of N, P, K, S are compound D (7% N:14% P<sub>2</sub>O<sub>5</sub>:7% K<sub>2</sub>O:6.5% S) applied as a basal fertilizer, and ammonium nitrate (AN), with 34.5% N, applied as a top dressing fertilizer (Ahmed et al., 1997). Compound Z containing 1% Zn has been on the market but the majority of smallholder farmers prefer to use standard macronutrient fertilizers which are cheaper. This has a negative feed-back on fertilizer manufacturers who lower production due to less demand. This consequently exacerbates micronutrients deficiencies especially in sensitive crops such as maize (Alloway, 2004). Zinc deficiency affect grain yield to a relatively greater extent compared to dry matter production probably due to impaired flower formation and pollen fertility among other factors.

## **2.4 Fertilizer types and their importance**

### ***2.4.1 Mineral fertilizer use in smallholder farms***

Greater productivity and consequently greater inputs of organic residues which help maintain soil organic matter (SOM) is associated with use of mineral fertilizers (Buol and Strokes, 1997). Soil organic matter has benefits for crop growth which result both from improvement in soil structure and ensuring a constant nutrient supply (de Ridder and van Keulen, 1990). However, mineral fertilizers currently manufactured do not cater for all the nutrients required

for improved plant growth and grain quality. Granitic sandy soils in smallholder farms of Zimbabwe are being depleted of nutrients such as Ca, Mg and Zn since fertilizers commonly used by farmers do not contain these nutrients. Although some liming material such as calcitic ( $\text{CaCO}_3$ ) and dolomitic ( $\text{CaMg}(\text{CO}_3)_2$ ) lime contain essential base elements such as Ca and Mg, smallholder farmers usually forego application of lime due to lack of purchasing power. This results in grain with low nutrient concentration. Due to the high price of mineral fertilizers, smallholder farmers purchase inadequate fertilizers and apply to the most productive fields at the expense of highly depleted, poor soils. This practice creates fertility “hot-spots” (Giller et al. 1997) or soil fertility gradients (Mtambanengwe and Mapfumo, 2005; Tittonell et al, 2005).

Application of mineral fertilizers to staple cereal crops is important in order to contribute to the Millennium Development Goal (MDG) 1 which is to eradicate extreme poverty and hunger between 1990 and 2015 (UN Millennium Project, 2005). Unlike parts of Asia and Latin America and the Caribbean which have been progressing to attain MDG1, most of Sub-Saharan Africa faces significant challenges in meeting the MDGs on almost every dimension of poverty, with many countries falling behind (Chen and Ravallion 2004). In his sharing of the fertilizer industry experience in finding innovative and easy replicable ways to increase agricultural productivity and sustainability in line with the MDGs’, Shriram (2010) mentioned that the fertilizer and Zn industries in India were working jointly to alleviate Zn deficiency in soils, crops and humans.

Because Zn deficiency is one of the leading risk factors for diseases in the developing world, the Zinc Nutrient Initiative was formed in India and China to work with non- governmental



organizations (NGOs), fertilizer companies, governments and farmers to increase productivity and nutritional content of crops through the use of Zn- based fertilizers. Shriram (2010) mentioned innovative partnerships as a way of improving food and nutrition security and public health. An example of such partnerships is the “Zinc Saves Kids Initiative” formed between the United Nations Children’s Fund (UNICEF) and the International Zinc Association (IZA) to improve the survival, growth and development of undernourished children ([www.zincsavekids.org](http://www.zincsavekids.org)). If such initiatives could be scaled up in countries facing challenges of Zn malnutrition, derived from inherently deficient soils, for example Zimbabwe, this would contribute much to the attainment of MDG 1.

#### ***2.4.2 Organic fertilizer use***

Organic materials are important sources of nutrients for many African smallholder farmers that lack financial resources to purchase mineral fertilizers (Palm et al., 1997). Organic fertilizers are important in that they provide other nutrients such as Ca, Mg and Zn which are not supplied in many traditional mineral fertilizers. These cations in organic materials are important for reducing problems of soil acidity and aluminum toxicity (Grant, 1967). Despite challenges associated with use of organic resources such as high labour costs as well as reduced quality and quantity (Giller et al., 1997; Vanlauwe and Giller, 2006), organic fertilizers will remain important because of other benefits which include residual fertility effects, local availability and suppression of witch weed (*Striga*) species. However, in the large scale commercial farming systems in Zimbabwe and some parts of Asia, intensive use of mineral fertilizers resulted in loss of familiarity of organic fertilizers (Giller et al. 1997). Cattle manure has been found to contain 112 mg Zn kg<sup>-1</sup> although concentrations vary due to the

nutritional composition of grazing lands (Zingore, 2006). When penned all day, one livestock unit (1 LU = 500 kg live mass) produces about 1.5 tonnes of recoverable manure per year (Rodel et al., 1980). Probert et al., (1995) estimated manure production rates of 1 t ha<sup>-1</sup> livestock unit<sup>-1</sup> yr<sup>-1</sup> in smallholder farming systems. Sharma et al., (2000) observed an increase in DTPA extractable Zn, iron (Fe), Cu and manganese (Mn) due to crop residue and farmyard manure incorporation compared to chemical fertilizers. Although cattle manure application is able to supply the much needed micronutrients, the usually recommended rates of more than 10 t ha<sup>-1</sup> (Mugwira and Murwira, 1997) are seldom achieved by farmers. The resource endowed farmers who have large herds of cattle and are able to apply the recommended rates of manure (Mtambanengwe and Mapfumo, 2005) have minimised the Zn deficiency problem on their farms. This may have negative implications on the field and farm scales. The redistribution of Zn in manure will not address the sustainability of crop production at the farming system level.

### ***2.4.3 Foliar fertilizers***

Foliar fertilizers are fertilizers that are applied to foliage to boost nutrient density in crops and to correct nutrient deficiencies ([www.davesgarden.com](http://www.davesgarden.com)). Before any foliar sprays it is important to collect leaf samples to determine deficiency. Foliar fertilization is best recommended for secondary and micronutrients such as S, Fe, Zn and Cu where plant requirements are relatively small. For major nutrients such as N, P and K, it is often necessary to use several foliar applications for improved crop yield and quality (Shahid et al., 1999). Foliar fertilizers should be compatible with pesticides and fungicides and should contain

chelates and sequestering agents to assure availability without precipitation of the macro- and micro-nutrients.

The main benefit of foliar spraying is that it can have up to a 90% efficiency rate of uptake in addressing nutrient deficiencies in annual crops, e.g. maize, as opposed to 10% efficiency from soil applications (Lingle and Holmberg, 1956). Also foliar fertilizers become immediately available in the plant because they are 100% water soluble. This makes them suitable for immediate correction of nutrient deficiencies. Foliar spraying stimulates plants to create exudates in the roots which increase activity of microbes and thus increases nutrient uptake from the soil (Kuepper, 2003). Soil amendments may take several days to take effect and the nutrients may be tied up with other elements and made unavailable to the plant. Certain soil conditions e.g. pH, excess moisture or cool temperatures may render a nutrient unavailable for plant uptake (Alloway, 2004). Besides adverse soil conditions, some nutrients such as Zn are immobile in the soil such that there is need to supplement soil applied fertilizers with foliar sprays (Witney, 1996).

Foliar sprays are a good supplement for improved flavours, sweetness, mineral density and yield of staple crops ([www.agriculturesolutions.com](http://www.agriculturesolutions.com)). During stages of fruit or grain development, a plant's requirement for nutrients exceeds its physiological capacity to extract nutrients (Rite grow, 2010). This might mean foliar applications could be timed to coincide with specific vegetative or fruiting stages of growth (Kuepper, 2003). Foliar fertilizers should contain little N which is used as an electrolyte and P for internal circulation because P has high phloem mobility (Ritegrow, 2010).

The disadvantage of foliar fertilization is that, unlike some soil applications such as organic fertilizers which leave residual fertility, foliar fertilizers do not produce substantial residual effects and application should be repeated every season (Cakmak, 2008). Foliar fertilization is labour intensive because application of small quantities is required in any single treatment to avoid burning of foliage and necrosis due to high concentrations of salts (Marschner, 1995; [www.aardappelpagina.nl](http://www.aardappelpagina.nl)). The cost of multiple applications can be prohibitive as the plants will immediately absorb nutrients applied. If one is to be cost effective, use of foliar fertilization alongside soil application will be necessary (Oosterhuis, 2007). Foliar fertilizers can only be applied in the early and late hours of the day. If foliar sprays are applied under hot conditions, fertilizers are highly likely not to be absorbed as the plant stomata will be closed. However, humidity, high temperatures and better crop growth conditions favour crop response to foliar application (El- Fouly and El- Sayed, 1997).

## **2. 5 Zinc importance to plants and symptoms associated with deficiency**

In plants, Zn acts as a metal component of many enzymes, for example carbonic anhydrase and dehydrogenases. Zinc deficiency restricts ribonucleic acid (RNA) synthesis such that protein production is restricted (Cakmak et al., 1999). Plants deficient in Zn are poor in proteins. Zinc deficiencies in soil affect legume-rhizobium symbiosis. This implies that soil nutrient availability is crucial when it comes to nitrogen fixation and legume establishment (Giller, 2001; O` Hara, 2001). Zinc is important for auxin production such that if auxin production is low, dwarfism and growth reduction occurs. Visible symptoms can only be realized in cases of acute deficiency. In cases of mild deficiency, hidden deficiency occurs where there may be a decrease in yield without any visible symptoms. This may go unnoticed

for several growing seasons. Hidden deficiency may depress plant yields by 50% (Katyal, 1972). In maize, deficiency symptoms include yellow streaks or chlorotic striping between veins in older leaves. Similar chlorosis appears in Mg, Fe and S deficiency. Unfolding of young leaves occurs when Zn deficiency becomes severe. These leaves might turn white or yellow, a case referred to as white bud in maize (Katyal and Randhawa, 1983).

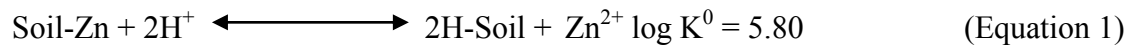
Apart from visual analysis, one can determine Zn deficiency through laboratory analysis or splitting the stem longitudinally to note the purple colour on nodes only in young plants. Shortening of internodes results in stunted growth and prolonged growth, for example, delay in silking in maize. Deficiency may be genetically affected, occurring more in short season varieties. Different crops have different sensitivities to Zn deficiency. Basing on crops mainly grown in Zimbabwe, sensitivity to Zn deficiency is in the order maize (*Zea mays*) > soybean (*Glycine max*) > wheat (*Triticum aestivum*) (Martens and Westerman, 1991). Zinc deficiency is prevented through application of Zn-containing fertilizers at a rate of between 3 - 20 kg Zn ha<sup>-1</sup>, above which there is a possibility of toxicity. Amount of fertilizer applied varies with method of application, which can be either banding or broadcasting (Murphy and Walsh, 1972).

Toxicity symptoms usually become visible at Zn concentration in the leaf of > 300 mg Zn kg<sup>-1</sup> leaf dry weight (DW), although some crops show toxicity symptoms at Zn concentrations < 100 mg Zn kg<sup>-1</sup> DW (Chaney 1993; Marschner, 1995). Toxicity thresholds can be highly variable even within the same species. Zinc toxicity symptoms include reduced yields and stunted growth, Fe-deficiency-induced chlorosis through reductions in chlorophyll synthesis and chloroplast degradation, and interference with P, Mg and Mn uptake (Chaney, 1993). Leaf

fall and disruption of soil microbe activity are other known Zn toxicity effects (www.spraygro.com.au).

## 2.6 Forms of Zn in soils

Zinc in soils is distributed over five pools namely the water soluble, the exchangeable pool, the organically bound pool, the non- exchangeable pool and the weathering primary minerals pool (Alloway, 2004). The water soluble pool is a very small portion with an average of around 50 – 80 mg kg<sup>-1</sup> (Kabata and Pendias, 1992). A direct proportion between Zn activity and proton activity imply that Zn solubility increases with a decrease in pH (Kiekens, 1995) as described in equation 1 below:



can be expressed as  $\log \text{Zn}^{2+} = 5.8 - 2\text{pH}$

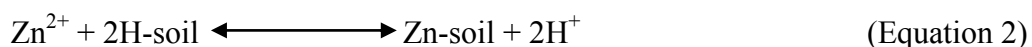
The exchangeable pool consists of ions bound to soil particles by electric charges. The organically bound pool comprises of ions adsorbed, chelated or complexed with organic ligands. The non- exchangeable pool consists of sorbed non- exchangeable ions on clay minerals and insoluble metallic oxides. The last pool comprises of weathering primary minerals, in particular the ferromagnesian minerals, augite, hornblende and biotite. The exchangeable and organic Zn fraction was found to be greater at pH values <7.0 (Sims and Patrick 1979). The availability of Zn to plants varies with the pool. Zinc in the water soluble and exchangeable fractions is readily available to plants while that associated with primary and secondary soil minerals remains relatively unavailable (Viets, 1962). Though the water soluble fraction is very small, the pool is very crucial in plant nutrition (Katyal and Randhawa,

1983). The relative amount of each of the above Zn forms differs considerably from one soil to the other. White (1957) studying distribution of Zn in Tennessee soils reported that between 1 – 7% of Zn was on exchange sites of clay minerals, 10-40% in organic matter or in resistant minerals, 20-45% in lattice positions of clay minerals while another 30-60% was associated with iron oxides. In another study conducted on granite derived sandy soils found in Zimbabwe, Tagwira (1991) indicated that on average, about 65% of Zn was the crystalline sesquioxide bound Zn, 14% was in the available form, 15% was organically bound while ~6% was in the hydrous metal oxide bound form. The fraction schemes help in understanding the soil chemistry of micronutrients.

## **2.7 Factors affecting the total Zn content of soils and availability to plants**

### ***2.7.1 Hydrogen – hydroxide ion concentration in soil (pH)***

Available soil Zn is highly pH dependent. The chemistry of Zn at varying pH values has been studied by Lindsay and Norvell (1969) and Lindsay (1972). Their results fitted the following equilibrium relationship which has been mentioned before as:



The solubility of Zn is highly pH dependent with high concentrations of Zn found in acid soils. Available Zn can decrease up to 100-fold for each unit increase in pH and tends to be greatly reduced in calcareous soils. Severe Zn deficiencies of 50 mg kg<sup>-1</sup> are noticed at pH > 6.0 (Katyal and Randhwa, 1983) against concentrations of up to 300 mg kg<sup>-1</sup> measured at pH < 6.0 (Alloway, 2004). In the soil solution, the predominant species at pH below 7.7 is Zn<sup>2+</sup>, at pH between 7.7 and 9.1, Zn(OH)<sup>+</sup> predominates and at pH above 9.1 the neutral Zn species

Zn(OH)<sub>2</sub> predominates (Tagwira, 1991). Certain farmer soil fertility management practices increase or decrease soil pH and can induce or alleviate Zn deficiency. Liming increases soil pH and depresses Zn availability while over-liming brings about severe Zn deficiency. Continuous use of acid fertilizers such as ammonium sulphate (NH<sub>4</sub>SO<sub>4</sub>) can have a combined beneficial effect on the nutrition of crops by both supplying N and also increasing Zn availability through the acidification of the soil. This results in desorption of Zn and improved root growth hence increased soil area from which the plant can draw nutrients from (Alloway, 2004). However some acid soils may contain toxic Zn levels.

### ***2.7.2 Phosphorus***

High soil phosphate levels are one of the main causes of Zn deficiency encountered in the world (Alloway, 2004). Phosphorus is one of the limiting nutrients in smallholder farms such that farmers tend to apply P fertilizers to replenish nutrient deficiencies (Tagwira, 1991). In the process of applying P fertilizers, plant uptake of Zn decreases sharply, often beyond a point which can be attributed to dilution effects due to crop enhancement, with an increase in the soil P content (Alloway, 2004). There are four mechanisms through which P can reduce Zn absorption from the soil. These are:

- i. Suppression of Versicular arbuscular mycorrhizae (VAM) infection of roots by high concentrations of P. Mycorrhizae effectively increase root surface area in the soil for absorption of several ions such as Zn and P in nutrient deficient soils. Previous studies have shown that inoculation of roots with a VAM produced a considerable infection in low-P plants compared to high-P plants, indicating enhanced plant compatibility to VAM fungi due to P deficiency (McArthur and Knowles, 1993). High P fertilization



might suppress infection of VAM hence reducing surface area for absorption of various nutrients including Zn. Mycorrhizae do not develop in soils that are saline, very dry, water logged or highly disturbed (Marschner, 1995).

- ii. Inhibition of Zn absorption from solution due to cations added with phosphate ( $\text{PO}_4^{2-}$ ) salts.
- iii. Inhibition of uptake of  $\text{Zn}^{2+}$  ions from soil solution due to  $\text{H}^+$  ions generated by  $\text{PO}_4^{2-}$  salts (see equation 3 below)



- iv. Absorption of Zn onto soil constituents enhanced by P as  $\text{HPO}_4^{2-}$  (Alloway, 2004).

In the plant, P in the form of either  $\text{H}_2\text{PO}_4^-$  or  $\text{HPO}_4^{2-}$  affects mobility and availability of Zn through four mechanisms which are:

- i. Inhibition of translocation of Zn from roots to shoots.
- ii. Reduction in the amount of soluble Zn.
- iii. Binding of Zn by P containing phytate which is the principal storage form of P in plants.
- iv. Leakage of P from membranes (Alloway, 2004).

An increase in P in the plant increases the plant's internal Zn requirement, a condition known as "P enhanced Zn requirement". However, in acid tropical soils, the risk of P-induced Zn deficiency increases when P application is accompanied by liming (Tagwira, 1991). Liming

will overcome aluminum toxicity and thereby increase root growth (Marschner, 1993). The sharp decrease in Zn concentrations in the soil solution combined with higher Zn requirements due to enhanced shoot growth requires an additional supply of Zn to prevent a reduction in growth caused by high P and liming.

### ***2.7.3 Organic matter***

Organic matter content in soil affects Zn solubility and its availability to growing crops. It affects Zn availability in soil either by forming soluble or insoluble complexes (Bunzl and Schimmack, 1991), depending on the proportions of fulvic acid, humic acid and humin in soil organic matter (SOM) fraction (Cheng and Allen, 2006). Low organic matter soils (<1%) are prone to Zn deficiency in calcareous soils of the arid and semiarid regions of the world (Alloway, 2004). High temperature and low rainfall increases the rate of organic matter decomposition resulting in reduced organic matter contents and consequently inadequate Zn levels in the soil. For sustainable crop production, which includes improved yield while sustaining the nutrient pool of the soil, organic matter concentrations should be at least 2.5 – 3.0% (Bhander et al., 1998). However, in granitic sandy soils, such values are unattainable due to the low aggregation, low clay content, low carbon protective capacity and sub-optimal application rates of organic resources. Upon decomposition, organic materials such as cattle manure, leaf litter, green manure and sewage sludge release substances which can form soluble complexes with Zn hence increase concentrations of available Zn in the soil. In England and Wales, cattle manure contributed 40% of total Zn added to soil (Alloway, 2004). Organic matter decomposition was found to give rise to chelating agents which contribute to Zn availability to growing plant roots (Lindsay, 1974; Tarkalson et al., 1998). More often Zn

deficiency is noted on sites where surface soil with high concentrations of organic matter has been scraped off, e.g. land-levelling activities for irrigation (Katyal and Randhwa, 1983). High organic matter soils such as muck and peat are exceptions as these soils show paucity of available Zn due to either inherently low Zn status or formation of organic complexes with the solid state organic matter (Alloway, 2004). Application of organic materials to soils could be one way of enhancing soil Zn availability (Milap et al., 1977).

#### ***2.7.4 Soil type and clay content***

Amount of nutrients vary in the soil depending on the parent rock. The total concentration of Zn in most soils ranges from  $<10 \text{ mg kg}^{-1}$  to  $\sim 300 \text{ mg kg}^{-1}$  (Katyal and Randhwa, 1983; Tagwira, 1991). Among igneous rocks, granite rocks have a low total Zn concentration of  $48 \text{ mg kg}^{-1}$  while basalt rocks have the highest concentration of  $100 \text{ mg kg}^{-1}$  (Wedepohl, 1978). During an appraisal of Zn status in Zimbabwean soils, Tagwira (1991) reported that the highest total Zn content of  $16 \text{ mg kg}^{-1}$  was measured from soils derived from Umkondo sandstone. Dolerite derived soils had a total Zn concentration of  $13 \text{ mg kg}^{-1}$ , alluvium soils  $11 \text{ mg kg}^{-1}$  while greenstone had  $9 \text{ mg kg}^{-1}$ . The dominant granite-derived and Kalahari sands had the lowest total Zn concentrations of  $6$  and  $3 \text{ mg kg}^{-1}$ , respectively. While parent material is the main factor affecting Zn concentrations, varying amounts of the micronutrient in soil have also been attributed to texture.

Red clay soils tend to have a higher concentration of micronutrients than sandy soils. This is mainly due to a decrease in carbon mineralization with increasing clay content (Mtambanengwe and Mapfumo, 2006). Red clay soils also have a compact structure and good water holding capacity, which result in them being less prone to nutrient leaching than sandy

soils. Poorly drained soils are also characterized by Zn deficiency due to an increase in pH in reducing conditions as well as antagonism reaction between  $\text{Fe}^{2+}$  which dominates in water logged conditions and  $\text{Zn}^{2+}$  (Alloway, 2004). Since most smallholder farms are located on granite derived sandy soils, there is need for external fertilization to ameliorate these inherently Zn deficient and highly leached sandy soils.

### ***2.7.5 Interaction of Zn with other nutrients***

Nutrient interactions affect Zn availability in soils and uptake by plants. If plant available Zn in soils is low, it is affected negatively by N, P, K, Ca, Fe, Cu, B and Mn (Marschner, 1995). Nitrogen appears to affect the Zn status of crops both by promoting plant growth and by changing the pH of the root environment. On smallholder farms, N is limiting, and farmers concentrate on application of N-based fertilizers rather than Zn fertilizers. It has been found that improvement in yield is possible through positive interaction of applying N and Zn fertilizers (Alloway, 2004).

Combined application of N and Zn can lead to Zn deficiency through a dilution factor brought about by increased growth due to N. This results in reduced concentration of Zn in edible portions of crops. Calcium, Mg and K are known to inhibit the absorption of Zn by plant roots as they tend to occupy same absorption sites on soil constituents (antagonism mechanism). Application of Ca containing fertilizers such as  $\text{CaCO}_3$  through liming, increases soil pH and decreases Zn content of plants mainly because Zn availability is low at high pH levels. In certain highly calcareous soils of Iran, high concentrations of B and low levels of available Zn may occur simultaneously leading to a complex nutritional disorder (Aref, 2011). In Zimbabwe, where application of N and P fertilizers is the common practice, there is need for

balanced fertilization to avoid such negative nutrient interactions on inherently N, P and Zn deficient soils.

## **2.8 Zinc nutrition in smallholder communities**

Cereal crops are a major source of energy and protein in developing countries and constitute up to 70% of daily calorie intake in rural areas (Cakmak, 2008). Legumes are also part of human diets in low income countries. Though cereals provide more energy and protein in developing countries than any other foods, the consumption of micronutrients decreases because these staple grains constitute the greater part of the diet than more nutrient dense foods such as meat and dairy products (Ranun, 2001). It has been found that complementary foods consumed in developing countries cannot supply enough nutrients, with animal products only able to supply enough Fe, Zn and Ca in diets (ACC/SCN, 2001). Animal source foods can provide micronutrients in greater amounts and more bioavailable forms compared to plant source foods but their intake is low in many poor communities (Siekmann et al., 2003). In Philippines, addition of chicken liver and egg yolk resulted in increased Fe and Zn content of maize based complementary foods (Perlas and Gibson, 2005). Unfortunately, lack of sufficient animal products in smallholder communities has resulted in growing dependence on cereals hence increasing the challenge of meeting micronutrient requirements.

Fresh fruits and vegetables such as spinach contain organic acids which promote bioavailability of micronutrients. In Zimbabwe, information on intakes and major food sources of Zn in local diets, as well as on the anti-nutrients dietary fibre and phytate are limited. Such data is essential for assessing the risk of inadequate intake of dietary Zn and for coming up with options of improving bioavailability of the nutrient in traditional foods. Micronutrient

malnutrition requires production of enriched foods as the majority of the population solely rely on staple cereal foods for improved nutrition.

## **2.9 Efforts to correct micronutrient deficiencies in food crops and humans**

Malnutrition remains a large and persistent problem in the developing world (Schofield and Ashworth, 1990; FAO, 2004; WHO, 2004). Many of the poor in lower income countries suffer from micronutrient deficiencies as their diet is cereal based. Cereal diets are not only low in micronutrients but are also sources of phytic acid and dietary fibre which inhibit absorption and retention in the human body, of nutrients such as Fe and Zn (Gibson, 1994a). An estimate of 1 in every 3 people globally has been found to be at risk of Zn deficiency (Brown et al., 2001) with consequences of deficiency including pregnancy complications, low birth weight and growth faltering in infancy and childhood (Gibson, 1994b). This therefore calls for strategies for improving the nutritional well being and health of humans. Several programs have been initiated to improve micronutrient nutritional status of target population. These include supplementation, food diversity, industrial food fortification and agricultural biofortification (Bouis, 2003; Pfeiffer and McClafferty, 2007).

### ***2.9.1 Supplementation***

About 450,000 children are at risk of dying every year due to the impact of Zn deficiency on diarrhoea, pneumonia and malaria such that an extra milligram of Zn everyday could make a significant difference (Black et al., 2008; [www.zinc.org/health](http://www.zinc.org/health)). About 20 mg of supplemental Zn is sufficient to stop diarrhoea and stave off further bouts for 3 months. Supplementation with Zn capsules can be a rapid and effective way of correcting micronutrient malnutrition on

an individual level but due to lack of education and infrastructure, this strategy has generally failed on a population level in developing countries (Graham et al., 2000). Though supplementation programs are cost effective, not many families can access such initiatives and supplementation is not recommended for children under the age of 12 years who unfortunately happen to be prone to Zn deficiency after weaning. This implies agronomic fortification may be a promising approach for addressing Zn deficiency in human nutrition to date.

### ***2.9.2 Food diversification***

To combat malnutrition in cereal based diets, animal source foods are often appropriate for supply of micronutrients (ACC/SCN, 2004) as nutrients in these foods exhibit greater bioavailability than those in plant sources (Randolph et al., 2007). Unfortunately, not many smallholder farmers own cattle or if they do, slaughtering animals for meat is infrequent, occurring only when animals become sick or unproductive, or for exceptional traditional ceremonies or hospitality (Scoones, 1992). Chicken ownership is relatively high, and chicken liver is known to result in greater increases in Fe and Zn content of cereal based diets (Agbon et al., 2009). While chicken liver may be another source of animal food to supply micronutrients in human nutrition, chicken meals are often too infrequent among smallholder households to make an impact on daily Zn requirements. Though dietary modification or diversification would seem to be a straight-forward and sustainable way to combat micronutrient deficiencies, changes in dietary habits require individual and social acceptance, intensive and costly education as well as availability of alternative foods at affordable cost (Ruel and Bouis, 1998).

### ***2.9.3 Industrial fortification***

Food or industrial fortification is a strategy that can be applied at national level without changing dietary patterns of people. Fortification of food has been effective in reducing micronutrient deficiency related morbidity and mortality in humans. However infrastructure, purchasing power or access to markets, and health care systems required in these approaches are often not available (Mayer et al., 2008). Some companies, for example Kapp Jack Milling Company in Harare, Zimbabwe, produce Zn fortified maize meal, but this product is not readily available on the market for most of the smallholder farmers. Successful implementation of fortified foods requires safe delivery systems, stable policies and continued financial support (White and Broadley, 2005; Gibson, 2006). In addition, food fortification programs rely on widely distributed, industrially processed food items usually unaffordable to half of the world's population living on less than US\$2/day and a further 30% who live on less than US\$1/day (Mayer et al., 2008). Much more investment is required in implementing food fortification programs and because of this, Zn interventions with fortified foods are still largely experimental (Khoshgoftarmanesh et al., 2009).

### ***2. 9.4 Biofortification***

To meet the world's demand for food, it is important to exploit genetic diversity of plants for enhanced productivity on poor soils. Selection and breeding of staple food crops which are efficient in uptake of micronutrients from the soil and increased loading in the seed combines benefits for both agricultural productivity and human nutrition (Khoshgoftarmanesh et al., 2009). Selection of genotypes which can tolerate low nutrient inputs (Graham and Rengel,



1993) or which can grow efficiently on soils with low phytoavailable micronutrients are the major components of biofortification.

Biofortification can be achieved by breeding or genetic engineering of crops (molecular biology and transgenic approaches) to come up with crop plants with improved or desired traits (Graham et al., 2000; Welch and Graham, 2004; White and Broadley, 2005). In this case, the plants have improved ability to accumulate Zn in potentially bioavailable forms in edible plant parts. Biofortification also involves increasing bioavailable micronutrient density in food plants by agricultural methods of crop cultivation (Frossard et al., 2000; Graham et al., 2001; Welch, 2002b). Molecular biology involves identification of promising parents and stable target traits across different agroecological zones. However, agronomic biofortification appears to keep sufficient amount of available Zn in soil solution and maintain adequate Zn transport to seeds during reproductive growth stages (Cakmak, 2008), and thus maybe a useful strategy in improving the nutritional wellbeing and health of humans.

### **2.10 Measurement of bioavailability of Zn in human diets**

Application of Zn fertilizers to cereal staples contributes significantly to increase in nutrient concentrations in the grain. However, bioavailability of nutrients such as Zn in human diets may be compromised by PA which is the major anti-nutritional component affecting bioavailability of Zn in human diets (Graham et al., 2001). Bioavailability of a nutrient is explained as the amount of a nutrient that can be potentially absorbed by humans after a meal and consequently be utilized for various metabolic processes in the body (Welch, 2002a). Phytate action involves precipitation of Zn as a Zn – phytate complex in the lumen of the

small intestines rendering Zn and P unavailable for uptake. In spite of this, phytase is an enzyme that hydrolyses phytic acid rendering it inactive towards Zn.

The phytic acid:Zn molar ratio is commonly used to estimate bioavailability of Zn in diets (Morris and Ellis, 1989). About 65 – 85% of P in plant derived foods is available as phytic acid which binds with Zn among other nutrients, and makes it less available for uptake (O'Dell et al., 1972, Alloway, 2004; Cakmak, 2008). Application of Zn fertilizers on Zn deficient soils is effective in reducing accumulation of phytic acid in plants, especially in the aleuron layer of seeds. By so doing, the phytic acid: Zn molar ratio is kept at low ratios of  $\leq 15$ . There is evidence that Ca may accentuate the effect of PA on Zn bioavailability and thus the molar ratio of Ca x PA:Zn has also been suggested as an indicator of Zn bioavailability in humans. Ellis et al. (1987) suggested that the Ca x PA:Zn ratio  $>200$  indicates poor Zn bioavailability.

### **2.11 Research on zinc in Zimbabwe**

In Zimbabwe, priority has been towards use of macronutrient- based fertilizers, hybrid seeds and application of lime to acid soils with little attention on micronutrients. A few studies that have been carried out on Zn and fertilizer recommendations were based on diagnosis of deficiency symptoms and on foliar analysis (Madziva, 1981). Seed dressing with ZnO was introduced to eliminate Zn deficiency. Although the method proved fruitful, constraints were to come up with machines used in planting treated seed. Studies by Tanner and Grant (1974) focused on the effectiveness of N, P, K fertilizer and lime as carriers of Zn for maize under field conditions. Maize yields increased after broadcast and spot application of the fertilizer. This resulted in production of zincated fertilizer and lime. The residual effect of Zn persisted

for 4 years (Tanner, 1975) which implies that micronutrients could be applied relatively cheaply to the soil. Zincated fertilizer placement in the planting hole eliminated Zn deficiency and promoted growth of young maize plants (Tanner, 1971).

The Zn status in Zimbabwean sandy soils and factors affecting Zn availability namely SOM, P, cation exchange capacity (CEC), pH and lime addition were assessed by Tagwira (1991). The findings showed that high rates of P, high pH and application of lime reduced the Zn concentration of maize plants. Application of 5 t ha<sup>-1</sup> cattle manure was found to supply ~0.5 g Zn ha<sup>-1</sup> (Tagwira, 1991). Green house pot experiments by Zingore (2006) showed maize yield response to be limited by Ca and Zn particularly in soils collected from fields away from the homestead (outfields) that rarely received cattle manure. Mukurumbira and Nemasasi, (1997) showed that plant nutrients limiting maize growth in Chivhu and Nharira Districts were in the order: N>P>Cu>Zn=Fe=Mg. The order suggests that Zn is an essential micronutrient which limits maize growth to the same extent as Mg.

## Chapter 3

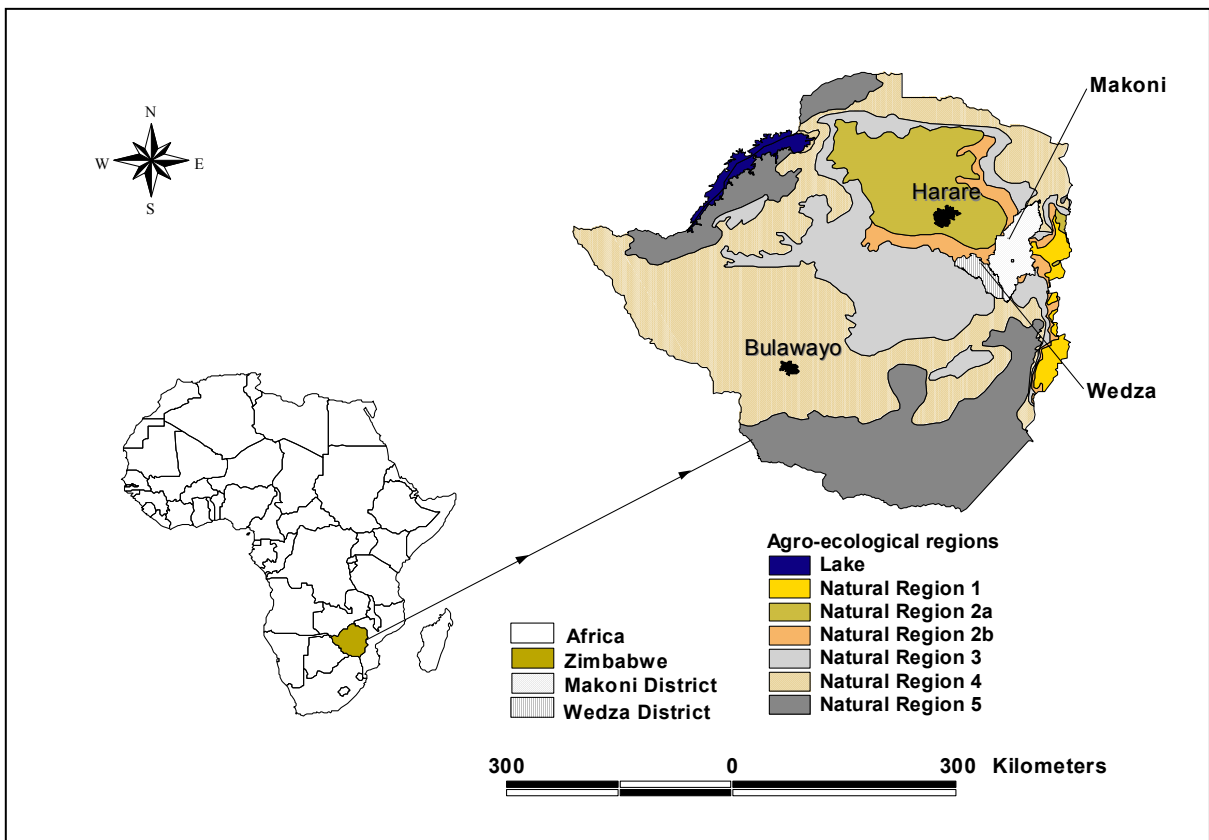
### General Materials and Methods

#### 3.1 Study sites

The study was conducted in Bingaguru (also known as Chinyika) ward of Makoni district (18° 13'S, 32° 22'E) and Goto ward of Wedza district (18° 41'S, 31° 42' E) in eastern Zimbabwe (Figure 3.1) between 2008 and 2011, under the auspices of the Soil Fertility Consortium for Southern Africa (SOFECSA) ([www.sofecsa.org](http://www.sofecsa.org)). It comprised of a soil fertility survey and two major experiments conducted on smallholder farmers' fields. Wedza, an old communal area with >80 years of smallholder settlement, is in Natural Region (NR) II receiving rainfall between 750 – 800 mm annum<sup>-1</sup>, while Chinyika is a post-independence resettlement area in NR III which receives 650 – 750 mm annum<sup>-1</sup>. Agro-zonation in Zimbabwe is defined in terms of mean annual rainfall during a unimodal season that occurs between November and March (Vincent and Thomas, 1961; Department of Surveyor-General, 1984).

Wedza is approximately 150 km south east of Harare and average farm holdings range from 1 ha to 3 ha per household. Makoni District is approximately 250 km east of Harare. The soils in both areas range from coarse sands to sandy clay loams classified as Arenosols and Lixisols (WRB, 1998) with <10% clay and <0.65% organic carbon. Formerly a large scale commercial farming area, Chinyika resettlement area was opened for smallholder agriculture by the Government of Zimbabwe during the first phase of decongestion of communal areas between 1982 and 1983 (Mtambanengwe and Mapfumo, 2006). Households have an average landholding of 6 ha, with maize (*Zea mays* L.) cropping being the dominant enterprise,

although there is a strong crop-livestock interaction with average cattle ownership of at least 5 cattle household<sup>-1</sup> (Chisora, 2006). Grain legumes, mainly groundnuts (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* [L.] Walp), are produced at a comparatively low scale. The natural vegetation in both study sites is dominated by tropical savannah woodland (miombo) trees of the genera *Brachystegia*, *Julbernardia*, *Combretum* and *Terminalia*.



**Figure 3.1** An illustration of Wedza and Makoni districts of Eastern Zimbabwe where on-farm maize trials were conducted

The study sites represented the dominant soil type in addition to rainfall regimes characterizing most of the smallholder farming systems in Zimbabwe. Crop production and livestock rearing are the key components of farming systems in Wedza and Makoni, with maize as the main crop and cattle as the main livestock component. Grain legumes such as

groundnuts and bambara groundnuts (*Vigna subterrenea* L.) are grown and rotated with maize. The major limitation to maize production is deficiency of soil N and P. Tobacco (*Nicotiana tabacum* L.) is grown as a cash crop in Makoni. Cattle, which are a major source of wealth, graze in communal grazing lands. Crop residues mostly maize stover collected from cropped fields are fed to cattle during the dry season and are also used as soil fertility ameliorants. When crop residues are used to improve soil fertility, they are either applied directly to the field or put in cattle kraal to increase the amount of manure obtained. In both districts, veld fires, prominent during the dry season months of August-November destroy some grazing areas and woodland litter from mountain ranges.

### **3.2 Main approaches used**

The study was conducted in three major phases:

- i. The different soil fertility management practices employed by farmers were identified using participatory research approaches and formal surveys. This allowed for determination of major domains within which soils were sampled and characterized for Zn status.
- ii. Different organic resources used by farmers which included cattle manure, woodland litter, and compost were then evaluated for Zn concentrations.
- iii. Experimentation on different Zn fertilizer formulations, applied either as basal or foliar and also used in combination with organic resources, was done on preliminary evaluated Zn deficient farmers' fields ( $<1.5 \text{ mg kg}^{-1}$  using the ethylenediaminetetraacetic acid (EDTA) method) (IITA, 1981; Dobermann and Fairhurst, 2000).

Maize grown on selected farmers' fields was monitored and at physiological maturity, grain samples were collected and analysed for grain nutrient concentration. Initial characterization of experimental sites was done to determine texture, pH, organic carbon (OC), exchangeable bases (Ca, Mg and K), and available P and total N using procedures described by Anderson and Ingram (1993). Maize grown on researcher managed fields was monitored for grain yield and then Zn concentrations were measured.

### **3.3 Soil analyses**

#### ***3.3.1 Determination of soil texture***

Soil texture was measured using the Hydrometer method (Gee and Bauder, 1986). Fifty grams of air dried soil was weighed into a 600 ml container and 100 ml of sodium hexametaphosphate (calgon) was added. Five hundred millilitres of distilled water was added to the mixture and put on an automatic rotational shaker overnight. The mixture was transferred into a 1000 ml measuring cylinder, and distilled water was added to the 1 litre mark. Using a plunger, the suspension was thoroughly mixed by moving it up and down for 1 minute. The hydrometer was gently placed into the cylinder, and its reading noted at 40 seconds and 5 hours after plunging. The temperature (°C) of the solution was also noted.

Calculations:

$$40 \text{ seconds (correctional reading)} = 2(40 \text{ seconds reading} - 40 \text{ seconds blank} + T)$$

$$5 \text{ hours (correctional reading)} = 2(5 \text{ hours reading} - 5 \text{ hours blank} + T)$$

where T = temperature corrections: For every °C above 20 °C (d), T = 0.3 x d; for every °C below 20 °C (d); T = -0.3 x d

d = Temperature difference

% sand = 100 – 40 seconds (correctional reading)

% silt = 40 seconds (correctional reading) – 5 hours (correctional reading)

% clay = 5 hours (correctional reading)

### **3.3.2 pH**

Soil pH was determined using the CaCl<sub>2</sub> method (Thomas, 1996). To a soil sample weighing 10 g, 25 ml 0.01M CaCl<sub>2</sub> was added. The resultant mixture was then shaken using a mechanical shaker for 30 minutes. After standing for 15 minutes, the suspension was shaken again and the electrode, (thoroughly rinsed free of the buffer solution), lowered into the suspension. When the reading on the pH meter had stabilized the displayed pH value was recorded (McNeal, 1982).

### **3.3.3 Total N determination**

Total N in soil samples was measured following digestion using the micro – Kjeldahl digestion method (Anderson and Ingram, 1993). The micro- Kjeidahl digestion method results in direct oxidation of organic matter through use of a digestion mixture that contains concentrated sulphuric acid, (H<sub>2</sub>SO<sub>4</sub>), 30% hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), lithium sulphate (Li<sub>2</sub>SO<sub>4</sub>) and selenium (Se) powder. Selenium powder is used as a catalyst and Li<sub>2</sub>SO<sub>4</sub> raises the boiling point of the mixture. An air dried soil sample weighing 0.5 g was weighed into a digestion tube followed by addition of 4.4 ml of digestion mixture. The resultant mixture was placed on a digester at 360 °C for 2 hours. The solution was allowed to cool and 25 ml of



distilled water added. A further 75 ml of distilled water was added and the solution was allowed to settle.

Total N in the sample was then determined colorimetrically at an absorbance of 655 nm. The % N in the sample was calculated as follows:

$$\% N = \{(\text{absorbance of sample} - \text{absorbance of blank}) \times F \times 0.01\} / \text{sample weight}$$

where F = the mean of (concentration of standards (ppm)/absorbance of standards)

### ***3.3.4 Total P determination***

Sample digestion for total P was the same as in determination of total N (see section 3.3.3). After digestion, 5 ml of sample were pipetted into a 50 ml volumetric flask followed by 20 ml of distilled water. To the mixture, 4 ml ascorbic acid ( $C_6H_8O_6$ ) was then added and the resultant solution mixed well. Distilled water was added to the mark and the solution left for 1 hour for full colour development. The samples and standards were read at 880 nm wavelength (Anderson and Ingram, 1993). The % P in the sample and standards was calculated as follows:

$$\%P = \frac{C \times 0.05}{W}$$

where C = concentration of P in sample; W = weight of sample.

### ***3.3.5 Available P analysis***

Extractable soil P was measured using the Olsen method (Olsen et al., 1954). Two and half grams of air-dried soil was placed into a 250 ml polythene shaking bottle followed by addition of Olsen extracting solution (0.5 M  $NaHCO_3$  at pH 8.5). The mixture was shaken on a

mechanical shaker for 30 minutes. The resultant suspension was filtered through Whatman No. 540 filter paper. To the filtrate (10 ml), 5 ml of 0.8 M boric acid ( $\text{H}_3\text{BO}_3$ ) and 10 ml  $\text{C}_6\text{H}_8\text{O}_6$  reagent were added and allowed to stand for 1 hour. The P content of the sample was then determined colorimetrically from a phosphorus-molybdate complex formed by addition of acidified ammonium molybdate ( $(\text{NH}_4)_2\text{MoO}_4$ ) (Okalebo et al., 2002). The absorbance of the sample and standards were read at 880 nm wavelength. The concentration of P in the sample was calculated as follows:

$$\text{P (mg kg}^{-1}\text{)} = \frac{(\text{A}-\text{B}) \times \text{V} \times \text{F} \times 1000}{1000 \times \text{W}}$$

where A = the concentration of P in the sample; B = the concentration of P in the blank; V = volume of extracting solution; F = dilution factor; W = weight of soil.

### ***3.3.6 Organic carbon determination***

Soil organic carbon was measured using the wet oxidation colorimetric method (Anderson and Ingram, 1993). One gram of soil sieved through a 2 mm sieve was weighed into a conical flask followed by addition of 10 ml potassium dichromate ( $\text{K}_2\text{Cr}_2\text{O}_7$ ). The resultant mixture was gently swirled until the sample was completely wet. To the mixture, 20 ml of concentrated  $\text{H}_2\text{SO}_4$  were added from an automatic dispenser and the resultant mixture gently swirled. The mixture was allowed to cool in a fume cupboard followed by addition of 50 ml 0.4%  $\text{BaCl}_2$ . The mixture was swirled and left to stand overnight, so as to get a clear supernatant solution. Total organic C in the sample and standards was then measured colorimetrically using a

BUCK Scientific 100 VIS spectrophotometer at 600nm wavelength. The % organic C in the sample was then calculated as follows:

$$\% \text{ organic C} = (K \times 0.1) / (W \times 0.74)$$

where K = sample concentration – mean blank concentration

W = weight of soil

### ***3.3.7 Exchangeable bases***

Exchangeable bases were determined using the 1 M acidified ammonium acetate (NH<sub>4</sub>OAc) method (Anderson and Ingram, 1993). An air dried soil sample weighing 10 g was placed into 150 ml plastic container to which 40 ml of 1 M acidified NH<sub>4</sub>OAc was added. The container was tightly closed and put on a reciprocating shaker for 1 hour. The solution was then filtered through a Whatman No. 540 filter paper into 250 ml flasks. Fresh NH<sub>4</sub>OAc was used to make up the flask to the mark. Twenty millilitres of the resultant solution were then pipetted into a 100 ml volumetric flask followed by addition of 20 ml of lanthanum chloride (LaCl<sub>3</sub>.7H<sub>2</sub>O). The concentration of K<sup>+</sup> was then determined by flame emission spectroscopy at 766.5 nm, and Ca<sup>2+</sup> and Mg<sup>2+</sup> by atomic absorption spectroscopy at 422.7 nm and 285.2 nm, respectively against a set of standards.

### ***3.3.8 Determination of available zinc***

The method for Zn determination depended on the pH of the soil. The methods of measuring available Zn commonly used in Zimbabwe are the ethylenediaminetetraacetic acid (EDTA) and hydrochloric acid (HCl) method. Ethylenediaminetetraacetic acid- extraction was used for

determination of soluble Zn as it has been frequently evaluated and produced the best correlation with maize growth in Zimbabwe (Madziva, 1981). Ethylenediaminetetraacetic acid is a chelating agent used in Zn determination in soils (Viets, 1962). Five grams of air dried soil were placed in a clean 250 ml plastic bottle fitted with an air-tight screw cap. Fifty millilitres of 1% EDTA were added to the soil and mixed on a reciprocating shaker for 1 hour. The suspension was filtered through Whatman # 540 filter paper. The filtrate was aspirated into an air acetylene flame of an atomic absorption spectrophotometer (AAS) which was used to read the wavelength of Zn at 213.9 nm.

### **3.4 Plant tissue analyses**

Plant tissue analyses involved analysis for total N, P, Ca, Mg, K, S and Zn concentrations in leaf and grain samples.

#### ***3.4.1 Determination of plant nitrogen***

Plant N was determined using the Total Kjeldahl Nitrogen (TKN) method which is based on the wet oxidation of organic material using  $\text{H}_2\text{SO}_4$  and digestion catalysts to convert organic N to ammonium form ( $\text{NH}_4^+$ ) (Okalebo et al., 2002). Sulphuric acid (10 ml) was added to 1 g of ground plant sample and  $\text{CuSO}_4$ -Se mixture was added as the digestion catalyst. The mixture was heated on a digestion rack until a colorless solution was obtained. This was transferred to a distillation flask where 50% of NaOH and dilute  $\text{H}_2\text{SO}_4$  were added. The mixture formed a blue colour complex. Steam distillation was done and the distillate collected in a conical flask with boric acid ( $\text{H}_3\text{BO}_3$ ). The mixture produced ammonia ( $\text{NH}_3$ ) which was trapped into a conical flask containing  $\text{H}_3\text{BO}_3$  and titrated against dilute  $\text{H}_2\text{SO}_4$ . Thymol blue was used as an

indicator and the end point reached when the mixture turned blue from pink. Plant N was read colorimetrically using a BUCK Scientific 100 VIS spectrophotometer at 650 nm.

#### ***3.4.2 Determination of plant phosphorus***

The method used to determine plant P was based on the wet oxidation of organic P using perchloric acid ( $\text{HClO}_4$ ) (Isaac and Johnson, 1985). A sample weighing 1 g was initially saturated with calcium acetate  $\text{Ca}(\text{C}_2\text{H}_3\text{OO})_2$  solution then ashed in a crucible at  $600^\circ\text{C}$  in a muffle furnace. Perchloric acid was added to the ash and the mixture placed in a water bath for 30 minutes. The contents of the crucible were transferred into a 100 ml volumetric flask using hot water to prevent the solution from crystallizing. The mixture was topped to the mark using distilled water. To enable colour development, a vanadomolybdate reagent was added. The solution was read at a wavelength of 400 nm using a Varian Spectra AA50 spectrophotometer.

#### ***3.4.3 Extraction and determination of Ca, Mg, K, S, Zn***

One gram of the sample was ashed overnight at  $500^\circ\text{C}$  in a furnace. The samples were allowed to cool at room temperature and 6 drops of concentrated nitric acid ( $\text{HNO}_3$ ) together with 6 ml of 25% HCl were added into the test tube. Drying under ultra violet (UV) light was done to allow oxidation to take place. Cooling of the sample was done for 30 minutes after which 6 ml of 25% of HCl was added to the mixture. The mixture was filtered into a 50 ml volumetric flask and topped up to the mark using distilled water. An AAS was used to read the different absorbances of Ca (422.7 nm), Mg (285.2 nm) and Zn (213.9 nm) and K (766.5nm) of the plant samples. Nutrient concentrations in maize shoots were interpreted as deficient, low or adequate using values suggested by Marschner (1995) and Mengel and Kirkby (2001) (Table

3.1). A different classification, deficient, low, sufficient or high (Walsh and Beaton, 1973) was used for Zn concentrations in maize ear leaf samples (Table 3.2).

**Table 3.1** Values used to interpret adequacy of nutrients in different fields, using nutrient concentration values in maize shoots at 4 weeks after emergence

Element	Deficient	Low	Adequate
N (%)	< 2.00	2.00 - 2.50	2.50 – 3.50
P (%)	<0.10	0.10 – 0.20	0.20 – 0.50
Ca (%)	<0.20	0.20 – 0.30	0.40 – 1.00
Mg (%)	<0.10	0.10 – 0.20	0.20 – 1.00
Zn (mg kg <sup>-1</sup> )	<15	15 - 20	20 - 70

Adapted from Mengel and Kirkby, 2001; Dobermann and Fairhurst 2000; Marschner 1995

**Table 3.2** Values used to interpret adequacy of Zn in maize ear leaf samples

Description of Zn status	Zinc concentration (mg kg <sup>-1</sup> )
Deficient	11
Low	15
Sufficient	15-70
High	>70

Adapted from Walsh and Beaton, (1973)

#### **3.4.4 Determination of maize grain nutrient concentration and uptake patterns**

Grain samples were corrected to 12.5% moisture and then ground in a Thomas – Wiley Model 4 (Thomas Scientific, USA) laboratory stainless steel mill, digested in HNO<sub>3</sub> and 50% H<sub>2</sub>O<sub>2</sub>. The maize grain samples were analyzed for N, P, Ca, Mg, K, Zn, Al, Cu, Mn and Fe concentrations (Anderson and Ingram, 1993). Phosphorus and Zn uptake in maize grain was calculated as nutrient concentration in the grain multiplied by grain yield (Shivay et.al, 2008).

### ***3.4.5 Determination of phytic acid in grain***

As mentioned earlier, 65 – 85% of P is available as phytic acid (O' Dell et al., 1972). Therefore in this study, PA was assumed at 65% of P in the grain and this figure was used to determine the PA: Zn molar ratio.

## Chapter 4

### Soil fertility management practices, soil Zinc status and maize grain nutritional value on smallholder farms in Eastern Zimbabwe<sup>§</sup>

#### 4.1 Abstract

Global soil zinc (Zn) deficiencies pose a serious threat to crop production and food nutrition. Approaches such as application of organic fertilizers that lead to formation of natural chelates resulting in slow but improved Zn availability, are possible avenues to alleviate deficiencies. With particular emphasis on Zn availability and uptake patterns a study was conducted during the 2008/09 cropping season to evaluate the effect of smallholder farmers' soil fertility management practices on soil chemical properties and maize (*Zea mays* L.) grain nutrient concentrations in Wedza and Makoni smallholder farming communities in eastern Zimbabwe. A preliminary survey conducted to characterize farmer soil fertility management practices showed that over 35% of interviewed farmers practiced legume –cereal rotations, with ground nut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L.) as the mostly grown legumes. Common to both areas, use of leaf litter in combination with mineral fertilizers occupied the least proportion of <10%. Extractable soil Zn from the different farmers' fields ranged from 0.50 – 2.43 mg kg<sup>-1</sup> with the highest EDTA soil Zn measured after application of leaf litter to maize. In both areas, combined use of organic and inorganic fertilizer produced maize grain yields of >2.1 t ha<sup>-1</sup>, sharply contrasting the non-fertilizer treatment which yielded <0.8 t ha<sup>-1</sup>. Up to 64% and 46% increase in grain Zn concentration was measured against the control in Wedza and Makoni respectively. Co-application of inorganic fertilizers with cattle manure or leaf litter, and legume-cereal rotations significantly influenced Zn uptake (P<0.01), with uptake of up to 48.5 g Zn ha<sup>-1</sup> measured in Wedza. The Phytic acid: Zn ratio used to predict bioavailability of Zn in humans was above 15 in both areas. The Ca x PA: Zn molar ratio was also above the threshold of 200 in all treatments with highest values recorded from legume –cereal treatments. A significant (P<0.05) strong positive linear relationship between EDTA extractable soil Zn and maize grain Zn concentration was evident in both areas (R<sup>2</sup> >0.80). These results suggest that current farmer soil fertility management regimes are inadequate to supply sufficient Zn to improve grain nutrition and also result in high concentrations of Zn inhibitors (phytic acid and Ca), hence should be supplemented with Zn- based fertilizers.

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## 4.2 Introduction

Maize production is the dominant cropping system in smallholder farming in Southern Africa (Kumwenda et al., 1996) and other parts of the world. Since the introduction of the ‘Green Revolution’ in Asia in the 1970s, cultivation of high yielding genotypes, improved agricultural mechanization and production of macronutrient fertilizers with low impurities of trace elements has resulted in higher crop production per unit area and with greater depletion of phyto-available micronutrients (Khoshgoftarmanesh, 2009). Besides the inherent deficiency of micronutrients on sandy to sandy loam soils which characterize much of the cereal growing areas of Southern Africa including Zimbabwe, (Grant, 1981), most micronutrient deficiency problems are exacerbated by the high demand of modern crop cultivars that quickly deplete the limited soil nutrients (Cakmak et al., 1998; Martens and Lindsay, 1990).

Possible avenues available to smallholder farmers for providing nutrients to soils and increase their density in edible parts of plant include crop sequences and intercrops with grain legumes, green manures and trees, better integration of crop residues and animal manure into the cropping system and use of soil and foliar fertilizers (Khoshgoftarmanesh, 2009; Roland et. al., 1998). In many countries, especially arid and semi-arid regions of the developing world, very little or no crop residue is left in the field and much is used as animal feeds or for fuel (Timsina and Connor, 2001). Crop residues are considered an important source of several micronutrients and it has been recorded that about 50 – 80% of Zn, Cu and Mn taken up by rice and wheat can be recycled through residue incorporation (Prasad and Sinha, 1995). In maize cropping systems, it has been found that approximately 2.5 g Zn is removed for every

tonne of maize stover removed (Archer, 1988). From these findings, it is evident that recycling of crop residues can help improve availability of soil micronutrients.

Crop rotation systems enhance micronutrient availability because the preceding crop may influence soil physical and chemical conditions that govern soil fertility and consequently affect the succeeding crop. Legumes may positively affect soil quality by improving soil physical properties which provide better root growth conditions resulting in enhanced uptake of immobile nutrients by roots (Khoshgoftarmanesh, 2009). Grain legumes normally grown in smallholder farms for soil fertility improvement, subsistence and marketing include groundnut (*Arachis hypogea* L.), cowpea (*Vigna unguiculata* L.), soybeans (*Glycine max* L.) and of late, sunnhemp (*Crotalaria juncea* L.) which is used as a green manure (Muza, 2003).

Use of cattle manure can also increase plant available nutrients and improve both the physical and biological characteristics of the soil (Stevenson, 1994). To aid the quality and quantity of cattle manure, smallholder farmers in Zimbabwe remove crop residues from arable land and place them in cattle kraals. This practise is bound to increase the micronutrient concentrations of manure as crop residues contain large amounts of micronutrients (Reddy et. al., 1988). Zinc concentrations in manure ranging from 112 – 580 mg kg<sup>-1</sup> dry matter (DM) have been reported in different countries where the variable concentrations have been attributed to feed quality and conversion efficiency of feed by the animals (Fleming and Mordenti, 1991; Menzi and Kessler, 1998; Zingore, 2006).

Organic materials have proved to be important sources of nutrient inputs for many African smallholder farmers (Palm et al., 1997; Mapfumo and Giller, 2001; Mtambanengwe and Mapfumo, 2006). Due to lack of financial resources and appropriate incentives to purchase

mineral fertilizers, farmers in Zimbabwe and other parts of southern Africa often resort to labour intensive soil fertility management options that include use of termitaria soil and collection of woodland litter (*mutsakwane*) for soil amelioration. The cost of applying recommended rates of fertilizers is often too high, with one 50 kg bag of mineral fertilizer costing between US\$30.00 and US\$40.00 (ZFC, 2012). Consequently, smallholder farmers resort to combined use of mineral and organic fertilizers. Co-application of fertilizers helps compensate for the limited quality and quantity of organic amendments as well as elevated prices of inorganic fertilizers.

Although studies have been conducted to determine the effects of different organic amendments on micronutrient deficiencies in soils (Tagwira, 1991; Zingore, 2006) and yields of staple crops, particularly maize (Mtambanengwe and Mapfumo, 2006), very few of these studies have determined the influence of farmer management practices on micronutrient levels in major food crops. Smallholder farmers are mainly concerned with management of nutrient resources to attain high grain yields, with little attention to improving nutritional quality of these grains. This raises concerns about how soil fertility research can integrate nutritional aspects into smallholder farmers' current agronomic practices. Hence, the current study pursued the following objectives:

1. To evaluate the effect of different farmer soil fertility management practices on available soil Zn status and maize grain yields.
2. To determine the effect of farmer soil fertility management practices on maize grain Zn concentration and uptake.

Implications of the emerging patterns on current crop fertilization strategies and human nutrition are discussed.

### **4.3 Materials and methods**

#### ***4.3.1 Identification and characterization of farmers' common soil fertility management practices***

Farmers' common soil fertility management practices and associated major nutrient resources were identified using key informant interviews and focus group discussions. The key informants comprised local extension workers, village heads and leaders of farmers' groups as well as local representatives of farmer associations. Focus group discussions were held during meetings organised by SOFECSA local committees in collaboration with extension workers. A check list was used to guide the focus group discussions, resulting in three major outcomes:

- i. Determination of Zn content in the range of nutrient resources available within and around the farm and commonly applied to maize: These included cattle manure, compost from household waste and crop residues, woodland litter and ash. Prior to the on-set of the 2008/09 cropping season, a preliminary study was conducted to make an appraisal of inherent Zn concentrations in these organic nutrient resources in the forms that they are used by farmers. The rationale was that if these materials showed varied Zn concentrations, then the patterns of their use by farmers would influence plant available soil Zn status. At least 20 replicated samples for each of the identified nutrient resources were collected from across randomly selected farms in Wedza and Makoni (see Section 3.1).

- ii. Identification of major soil fertility management practices influencing maize production in the two study areas: These management practices were then used to define domains within which farmers could be classified. The resultant management domains included use of cattle manure or woodland litter in combination with mineral fertilizer, rotations involving mainly nitrogen-fixing grain legumes and maize, and sole application of NPK basal and N top dressing fertilizers (Table 4.1). The practices apparently reflected integrated soil fertility management (ISFM) options that farmers were prioritizing in the recent years based on their participation in SOFECSA research for development initiatives aimed at improving soil productivity for household food security. However, farmers also emphasized that a high number of their fields did not receive any external nutrient inputs, and such fields were used as controls. Therefore these domains were evaluated for plant available soil Zn status.
- iii. Defining the criteria to categorize farmers according to identified management domains: Basing on their experience, farmers were able to define different levels of management required to influence crop yields under each of the identified domains. Apart from farmer criteria, information was also drawn on literature from previous studies in the same area to determine optimum frequencies and rates for organic resource use on sandy soils (Mtambanengwe and Mapfumo, 2008). For example, a farmer was only considered to be a cattle manure user if he/ she used application rates of at least  $5 \text{ t ha}^{-1}$  within a period of three years on a given field (Table 4.1). Such quantities were estimated on the basis of number of scotchcart loads per given area versus influence on yield as observed by farmers. To ensure application of  $5 \text{ t ha}^{-1}$ , farmers applied an equivalent of 14 loads  $\text{ha}^{-1}$  using their standard scotchcart with a capacity of 350 kg manure load<sup>-1</sup>.

With respect to legume-based crop rotations, farmers considered the attainment of at least 1.0 t ha<sup>-1</sup> grain yield by a selected legume in the preceding season as a precondition for effective rotational benefits (Table 4.1; also see Kanonge et al., 2009). Selected fields constituting the sole mineral fertilizer treatment were those that received the recommended mineral fertilizer application rate of 300 kg ha<sup>-1</sup> Compound D (7N:14P<sub>2</sub>O<sub>5</sub>:7K<sub>2</sub>O) and 200 kg ha<sup>-1</sup> ammonium nitrate (34.5% N) to supply 90 kg N ha<sup>-1</sup> and 18 kg P ha<sup>-1</sup>, respectively (AGRITEX, 1985; Mapfumo and Mtambanengwe, 2004).

**Table 4.1** Common soil fertility management practices as recognised by smallholder farmers in Wedza and Makoni districts of Zimbabwe

Management practice	Characteristics
Non-fertilized control	Comprised fields that had been consecutively cropped to maize in the previous three seasons, but with no fertilization
Maize after legume	Area under maize was supposed to be the same as area under legume in the previous season. Field was considered to have effective rotational benefits if legume grain yields of at least 1 t ha <sup>-1</sup> were obtained.
Cattle manure + mineral NPK	Organic fertilizer application rate of at least 5 t ha <sup>-1</sup>
Leaf litter + mineral NPK	Organic fertilizer application rate of at least 5 t ha <sup>-1</sup>
Mineral NPK only	Farmer applied a rate of about 90 kg N ha <sup>-1</sup>

#### *4.3.2 Assessment of soil zinc status as influenced by soil fertility management practices*

To determine the distribution of the identified soil fertility management practices among farmers, and assess their relative influence on plant available soil Zn status, a questionnaire survey was designed and implemented during the dry period prior to the 2008/09 cropping season. Building on findings from the focus group discussions and key informants, 120 households were randomly sampled from across the study areas using village lists provided by extension and local councillors. The survey emphasised on how farmers used named ISFM

options in their fields over the past three consecutive seasons (years), and with a particular focus on maize. The proportions of farmers commonly using different management practices were then established. This resulted in categorization of farmers into the management domains within which field sites were selected for evaluation of soil Zn status and crop monitoring.

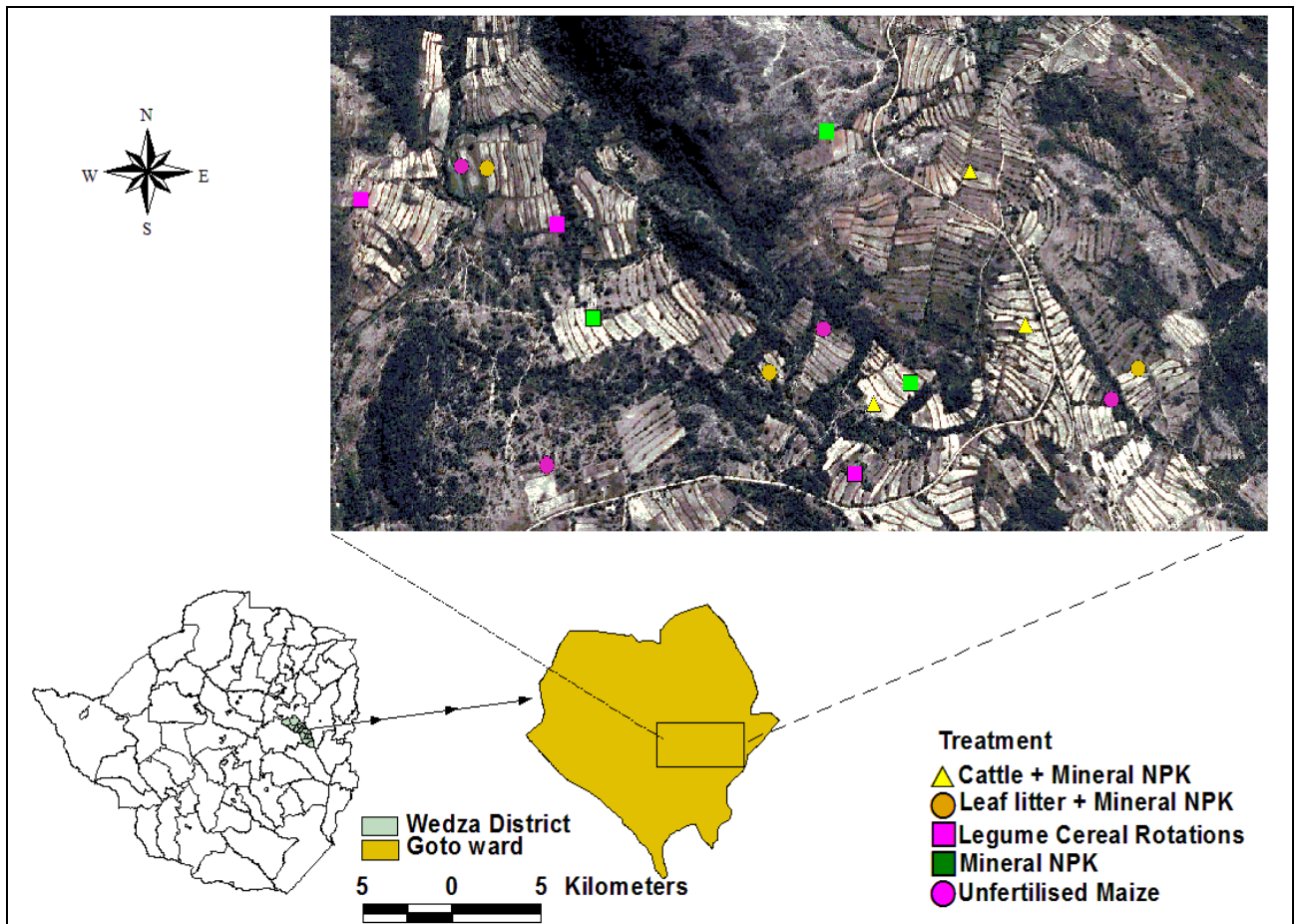
#### ***4.3.3 Soil sampling and laboratory analysis***

The soil samples were collected during the month of October, 2008 from a depth of 0 – 20 cm using an auger by randomly sampling 10 points from each target field. The samples were air-dried and sieved through a 2 mm sieve. Soil samples collected to represent each management domain were analyzed for soil Zn availability and other physico-chemical properties using methods and procedures mentioned in Chapter 3. The EDTA-extractable soil Zn was used as a proxy for plant available Zn consistent with previous studies revealing a strong correlation between the two parameters (Coffman and Miller, 1973; Madziva, 1981). Distribution of selected farms in each study area is highlighted in Figures 4.1 and 4.2.

#### ***4.3.4 Organic nutrient resources sampling and laboratory analysis***

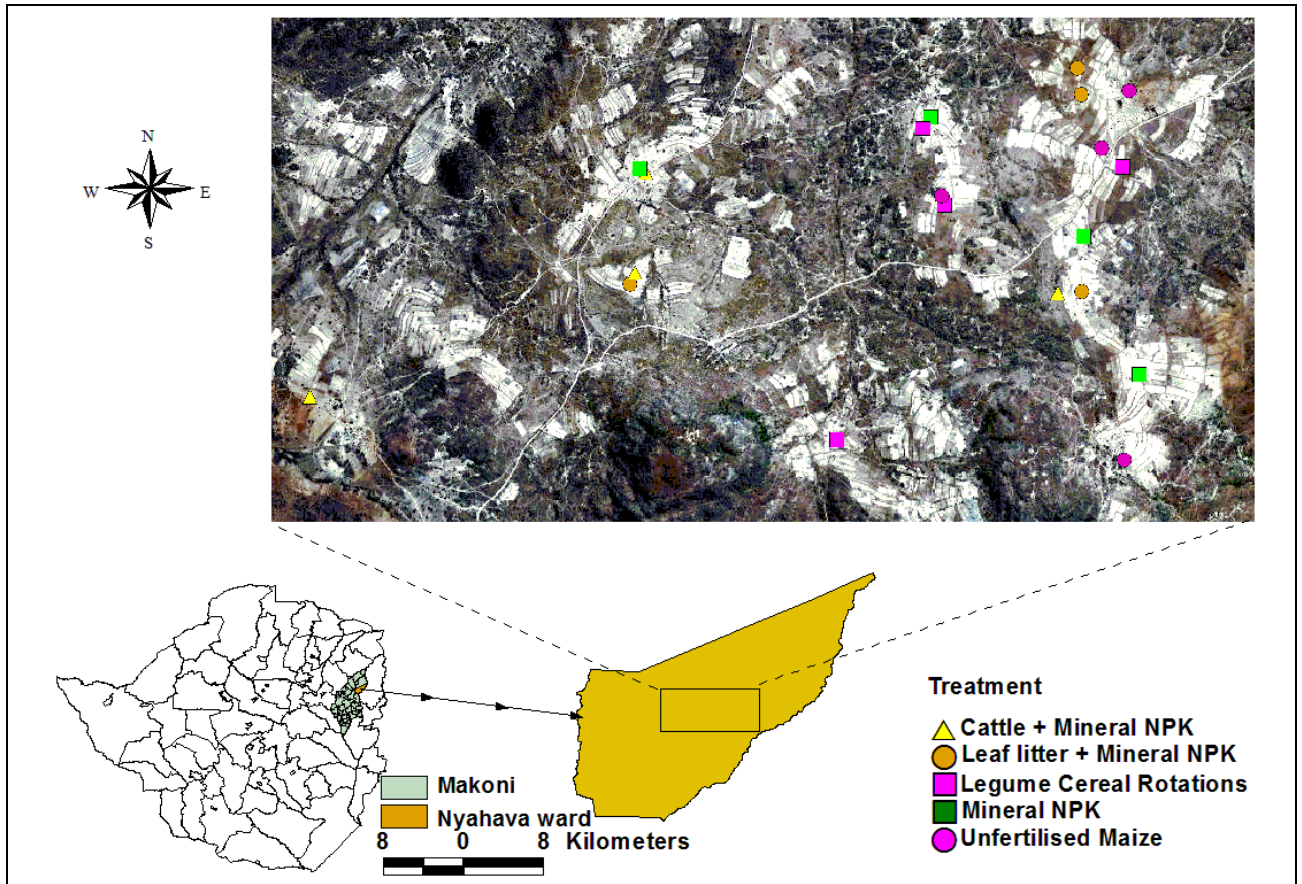
The different organic nutrient resources (Table 4.2) were collected from identified fertility management domains. About 100 g of each organic nutrient resource was sampled from each of the management domain and placed in a sampling bag. The amendments were air-dried and total N was determined using the Kjeldahl procedure as described in Chapter 3 (Okalebo et al., 2002). Total P was analysed using the molybdate-vanadophosphoric acid method (Anderson and Ingram, 1993). Ash content was determined by ashing the samples in a muffle furnace at 450° C overnight. Samples were allowed to cool, after which a few drops of deionised water

were added and ashing was continued for another 1 hour. The residue was weighed and ash determined on dry matter basis. Organic C was determined by Walkley-Black method (Okalebo et al., 2002). Available Zn was determined using the aqua regia method.



**Figure 4.1** Selected farmers' fields distribution in Goto Ward, Wedza District





**Figure 4.2** Selected farmers' fields distribution in Nyahava Ward, Makoni District

#### ***4.3.5 Determination of maize yield performance and Zn uptake patterns***

At the start of the 2008/09 cropping season, farmers were provided with maize seed, SC 513, a local early-to-medium maturity cultivar that takes about 140 days to physiological maturity. With the help of local extension, farmers planted and managed the maize using general agronomic recommendations for each agro-ecological zone (AGRITEX, 1985).

Maize grain yields were quantified at physiological maturity from three replicate net plots measuring 9 m<sup>2</sup>. Harvested maize was air-dried, shelled and grain yield determined at 12.5% moisture content. Subsamples of maize grain were ground in a stainless steel Thomas – Wiley Model 4 Laboratory mill (Thomas Scientific, USA) and analyzed for total Zn, N, P, Ca, Mg

and K following digestion with nitric acid (HNO<sub>3</sub>) and 50% hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) (also see Section 3.4.4). Zinc uptake was quantified by multiplying the grain Zn concentration and yield on a dry weight basis.

#### **4.4 Statistical analyses**

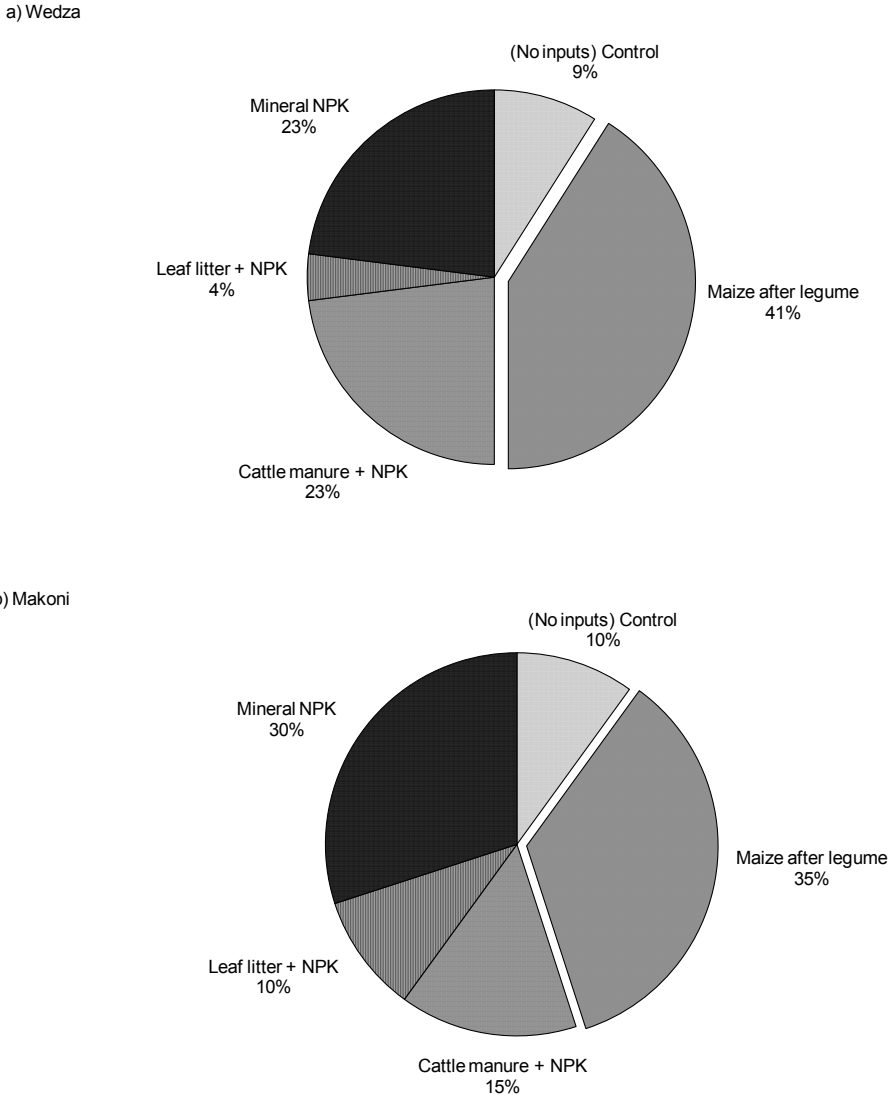
The effect of farmer soil fertility management practices on grain yield, grain nutritional value and soil physico-chemical properties was examined using analyses of variance (ANOVA) with GENSTAT version 13 statistical package (Lawes Agricultural Trust, Rothamsted Experimental Station, U.K). During the ANOVA, farmers were used as replicate blocks while the least significant difference (LSD) at P = 0.05 was used to differentiate between statistically different means. Relationship between grain Zn concentration and extractable soil Zn was explored with simple regressions using Sigma Plot version 10.0 (SPSS, Chicago, IL. USA).

#### **4.5 Results**

##### ***4.5.1 Distribution of soil fertility management practices among farmers***

Grain legume – cereal rotations was the predominant soil fertility management domain employed by most farmers in the two study areas (Figure 4.3). The results indicated that at least 41% of the households in Wedza and 35% in Makoni used legume-cereal rotations in a relatively systematic way. It was apparent that most smallholder farmers across the study areas understood the principles of legume – cereal rotations from their participation in SOFECSA learning alliances, hence the relatively high proportion of farmers using this practice. In Makoni, about 30% of the farmers used mineral fertilizers (NPK), making this management domain the second most important after the legume – cereal rotations. In Wedza, about 23% of

the farmers applied some form of mineral fertilizer. About 15-23% of the farmers in both study areas combined cattle manure with NPK mineral fertilizer. Use of cattle manure in combination with mineral fertilizers was apparently common among resource endowed farmers who owned relatively large herds of cattle. Approximately 10% of the farmers did not apply any external nutrient inputs to their maize crop (Figure 4.3). Woodland litter appeared to be the smallest domain, accounting for only 4% in Wedza and <10% in Makoni.



**Figure 4.3** Proportion of common soil fertility management practices by farmers.

#### 4.5.2 Nutritional composition of organic resources accessible to farmers

Chemical characterization of the organic resources available to farmers showed that they contained relatively high concentrations of Zn. Woodland litter contained 86 mg Zn kg<sup>-1</sup>, almost four times more than cattle manure (Table 4.2), suggesting its potential as a source of Zn for crops under farmers' current crop production circumstances. Compost and household ash, both commonly applied by farmers around homesteads, also exhibited high concentrations of 56 and 236 mg Zn kg<sup>-1</sup>, respectively. It was therefore apparent that systematic application of these organic resources would most likely influence availability of Zn to plants growing in these poor soils.

**Table 4.2** Zinc concentration and general chemical characteristics of organic nutrient sources collected from different management domains within smallholder farms in eastern Zimbabwe

Amendment	Total Zn <sup>a</sup> mg kg <sup>-1</sup>	Total N <sup>b</sup>	Total P <sup>c</sup>	Total Ca <sup>a</sup> %	Total K	Organic C <sup>d</sup>	C:N ratio
Cattle manure	22.5 (113)	0.8 ± 0.01	0.26	1.37	0.11	22.0	29.6 ± 1
Charcoal	90.5 (453)	Trace	0.16	nd	0.12	55.8	nd
Compost	56.0 (280)	1.0 ± 0.02	0.02	nd	0.88	12.8	12.4 ± 0.5
Leaf litter	86.0 (430)	0.9 ± 0.01	0.03	1.63	0.26	40.7	40.5 ± 3
Mineral fertilizer	nd	34.5	6.1	nd	5.8	na	na
Unamended soil	<1.5	0.02 ± 0.01	3.5	0.7	0.2	0.3	15.0 ± 0.8
Wood - ash	236 (1180)	Trace	0.54	nd	0.03	>90	nd

Procedures by: <sup>a</sup>Aqua Regia, <sup>b</sup>Kjeldahl procedure, <sup>c</sup>Molybdate – vanadophosphoric acid method, <sup>d</sup>Walkly-Black method; nd – not determined; na – not applicable. Figures in parentheses denote potential Zn added (g) through application of 5 t ha<sup>-1</sup> organic material

#### 4.5.3 Effect of farmers' soil fertility management practices on soil Zn status

The different soil fertility management practices used by farmers only exhibited significant (P<0.05) effects on available soil Zn, P and Ca, with no influence on all other measured soil chemical parameters (Table 4.3). Plant available soil Zn concentration ranged from 0.5-0.7 mg

kg<sup>-1</sup> on fields receiving no fertilization to 2.4 mg kg<sup>-1</sup> on soils amended with woodland leaf litter. Consistently, soils collected from unfertilized fields and those receiving only mineral NPK fertilizers had the lowest Zn concentrations with <1.0 mg kg<sup>-1</sup>. On the other hand, available soil P was consistently low, ranging from 3.5 mg kg<sup>-1</sup> in unfertilized fields to 9.1 mg kg<sup>-1</sup> for fields receiving combinations of cattle manure and mineral fertilizer (Table 4.3). The management domain involving grain legume-maize rotations consistently gave comparable chemical properties to organic-resource based treatments and apparently exhibited relatively high concentrations of Ca and Mg. For example, legume – maize rotational treatments had the highest Ca concentrations of 1.7-1.9 cmol<sub>c</sub> kg<sup>-1</sup> compared to unfertilized treatments which only had between 0.7-0.9 cmol<sub>c</sub> kg<sup>-1</sup>.

#### ***4.5.4 Soil fertility management effects on maize grain yield***

Maize grain yields varied significantly under the different soil fertility management domains (P <0.05). The highest maize yields were achieved when cattle manure was used in combination with mineral fertilizer, out yielding the control by between 189-350% across the study areas (Figure 4.4). Application of woodland litter produced 1.6 - 1.9 t ha<sup>-1</sup> of maize yield and was comparable to cattle manure. In Makoni, grain legume – based rotations in combination with mineral fertilizer more than doubled maize grain yields to about 1.6 t ha<sup>-1</sup> with respect to the control but did not differ significantly from the sole mineral fertilizer domain. The non – fertilized treatment domain consistently produced the lowest yields of between 0.5 -0.8 t ha<sup>-1</sup> (Figure 4.4).

**Table 4.3** Effect of different management practices on soil chemical properties in a) Wedza and b) Makoni.

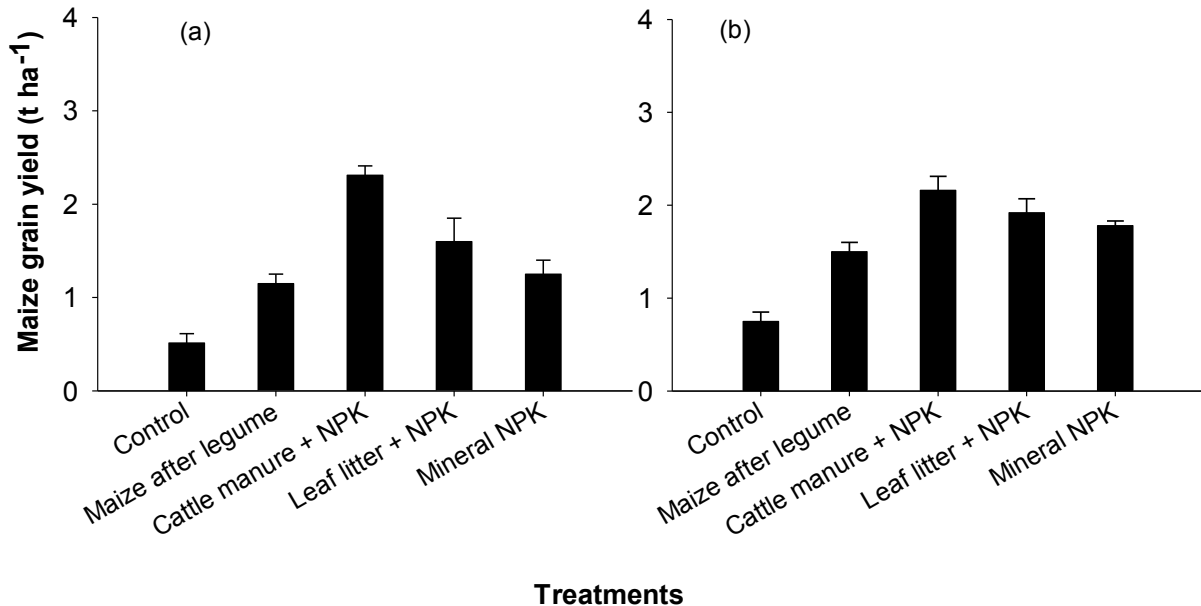
Wedza							
Treatment	Available Zn mg kg <sup>-1</sup>	Available P	Ca cmol <sub>c</sub> kg <sup>-1</sup>	Mg	Total N %	Organic C	pH CaCl <sub>2</sub>
Unfertilized maize	0.7 <sup>a</sup> (0.5 – 0.8)	4.0 <sup>a</sup>	0.7 <sup>a</sup>	0.5	0.02	0.30	4.2
Maize after legume	2.1 <sup>bc</sup> (1.8 – 2.9)	9.0 <sup>c</sup>	1.9 <sup>c</sup>	0.9	0.05	0.40	4.7
Cattle manure + NPK	1.5 <sup>b</sup> (1.3 - 1.8)	9.0 <sup>c</sup>	1.3 <sup>b</sup>	1.1	0.05	0.50	5.1
Leaf litter + NPK	2.4 <sup>c</sup> (2.4 – 2.6)	8.0 <sup>c</sup>	1.7 <sup>bc</sup>	0.8	0.03	0.60	4.9
Mineral NPK only	0.9 <sup>ab</sup> (0.8 – 1.4)	6.0 <sup>b</sup>	1.1 <sup>a</sup>	0.7	0.04	0.39	4.4
Mean	1.55	7.1	1.3	0.8	0.04	0.43	4.6
SED	0.3	0.9	0.2	0.2	0.01	0.13	0.4
F test	**	**	**	ns	ns	ns	ns
Makoni							
Treatment	Available Zn mg kg <sup>-1</sup>	Available P	Ca cmol <sub>c</sub> kg <sup>-1</sup>	Mg	Total N %	Organic C	pH CaCl <sub>2</sub>
Unfertilized maize	0.5 <sup>a</sup> (0.2 – 0.8)	3.0 <sup>a</sup>	0.9 <sup>a</sup>	0.6	0.02	0.28	4.1
Maize after legume	1.6 <sup>b</sup> (1.1 – 2.0)	9.0 <sup>bc</sup>	2.1 <sup>d</sup>	1.2	0.03	0.53	4.8
Cattle manure + NPK	1.5 <sup>b</sup> (1.1 – 1.8)	10.0 <sup>c</sup>	1.6 <sup>c</sup>	1.3	0.05	0.61	5.2
Leaf litter + NPK	2.3 <sup>b</sup> (1.1 – 3.0)	9.0 <sup>bc</sup>	1.9 <sup>d</sup>	0.9	0.02	0.53	4.8
Mineral NPK only	0.9 <sup>ab</sup> (0.7 – 1.3)	8.0 <sup>b</sup>	1.3 <sup>b</sup>	0.9	0.03	0.35	4.6
Mean	1.36	7.6	1.6	1.0	0.03	0.46	4.7
SED	0.4	0.8	0.1	0.2	0.01	0.11	0.4
F test	**	**	**	ns	ns	ns	ns

Extractable Zn and P were considered to be directly correlated to plant availability. \*\* means significant treatment differences at P<0.01; ns = not significantly different at P<0.05; Figures in parentheses denote ranges.

#### 4.5.5 Soil fertility management effects on grain Zn concentration and uptake

Maize grain Zn concentration was significantly (P<0.05) influenced by farmer soil fertility management practices in Wedza (Table 4.4). However, no such significant differences were observed in Makoni. Highest Zn concentrations of 19 to 23 mg kg<sup>-1</sup> obtained in Wedza were

from the management domain involving combined application of leaf litter and mineral fertilizer.

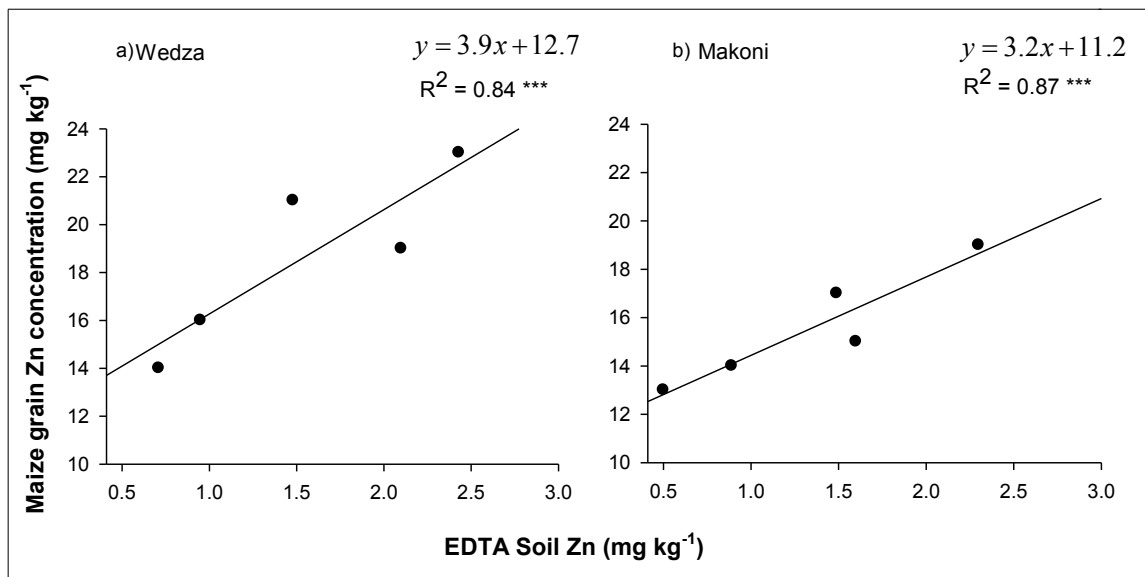


**Figure 4.4** Maize grain yields attained in farmers' fields during the 2009/10 growing season in (a) Wedza and (b) Makoni. Vertical bars represent standard error of mean (SEM).

Combined use of cattle manure and mineral fertilizer produced Zn concentrations of between 17 – 21 mg kg<sup>-1</sup>, and this was not significantly different from the treatment domain involving grain legume-maize rotations. Both these treatment domains consistently out-performed the sole mineral fertilizer and control domains across the study areas (Table 4.4). The unfertilized treatment domain had the lowest maize grain Zn concentration of between 13 - 14 mg kg<sup>-1</sup>. In both study areas, there was a significant linear relationship between EDTA-extractable soil Zn and maize grain Zn concentrations ( $R^2 > 0.80$ ), with maize grain Zn concentration increasing with an increase in soil Zn (Figure 4.5). Overall, maize grain Zn uptake in Wedza ranged between 7.1 to 48.5 g Zn ha<sup>-1</sup>, while a narrower range of 9.8 to 36.9 g Zn ha<sup>-1</sup> was obtained in Makoni (Table 4.4). Maize under combined use of cattle manure and inorganic fertilizers had

the highest Zn uptake in both study areas, yielding up to six times the amount taken up under the unfertilized control treatment domain.

The different management domains also exhibited significant ( $P < 0.05$ ) differences in maize grain P concentration, with the legume-cereal rotation giving the highest concentration of  $3.5 \text{ g P kg}^{-1}$  in Wedza (Table 4.4). However, cattle manure, woodland litter and sole mineral fertilizer management domains showed no significant differences. In Makoni, maize obtained from the sole mineral fertilizer treatment had the highest grain P concentration, superseding the unfertilized maize by up to 24%. Apart from the unfertilized control which exhibited the lowest P concentration, the rest of the management domains did not show significant differences in this study area (Table 4.4). The management domain involving grain legume-cereal rotations exhibited relatively high Ca concentrations which ranged from  $49.2$  to  $76.1 \text{ mg kg}^{-1}$ .



**Figure 4.5** Relationship between maize grain Zn concentration and EDTA-extractable Zn in a) Wedza, b) Makoni. \*\*\* means significantly related at  $P < 0.05$ .



**Table 4.4** Zinc, Ca and P concentration in maize grain and Zn uptake as influenced by farmer management practices in Wedza and Makoni smallholder farming areas in Zimbabwe

Treatment	Wedza				Makoni			
	Zn (mg kg <sup>-1</sup> )	Ca	P (g kg <sup>-1</sup> )	Zn uptake (g ha <sup>-1</sup> )	Zn (mg kg <sup>-1</sup> )	Ca	P (g kg <sup>-1</sup> )	Zn uptake (g ha <sup>-1</sup> )
Unfertilized maize	14 <sup>a</sup>	37.0	2.7 <sup>a</sup>	7 <sup>a</sup>	13	50.1	2.6 <sup>a</sup>	10
Maize after legume	19 <sup>b</sup>	49.2	3.5 <sup>c</sup>	22 <sup>a</sup>	15	76.1	3.0 <sup>b</sup>	23
Cattle manure + NPK	21 <sup>b</sup>	42.9	3.4 <sup>c</sup>	49 <sup>b</sup>	17	58.2	3.0 <sup>b</sup>	37
Leaf litter + NPK	23 <sup>c</sup>	44.4	3.4 <sup>c</sup>	37 <sup>b</sup>	19	60.6	2.9 <sup>b</sup>	37
Mineral NPK only	16 <sup>a</sup>	40.6	3.2 <sup>b</sup>	20 <sup>a</sup>	14	57.4	3.4 <sup>c</sup>	25
Mean	18.5	42.8	3.2	27	15.4	60.5	3.0	26
SED	1.7	9.3	0.1	8	2.2	18.4	0.1	9.5
F test	*	ns	*	*	ns	ns	*	ns

ns = treatments not significantly different. Means followed by same letters within the column did not differ significantly at P <0.05.

#### ***4.5.6 Effect of soil fertility management domains on indicators of Zn bioavailability***

An analysis of the effects of different management regimes on phytic acid to zinc (PA: Zn) molar ratio showed that the treatments had a significant ( $P < 0.05$ ) influence (Table 4.5). The PA: Zn molar ratio ranged from 96 to 158 and this substantially exceeded the known critical value of  $< 15$ .

Maize produced under sole mineral fertilizer exhibited relatively higher PA: Zn molar ratios of 130 - 158 than unfertilized treatment which gave a range of 125 to 130 (Table 4.5). Combined application of mineral fertilizer with either cattle manure or woodland litter resulted in the lowest PA: Zn molar ratio, but even these still exceeded the critical value of  $< 15$ .

There were, however, no significant treatment effects on (Ca x PA): Zn molar ratio, another commonly used indicator for Zn bioavailability (Table 4.5). The Ca x PA: Zn molar ratio ranged from 4 266 to 9 893 and was extremely high relative to the known critical values of  $< 200$ .

The observed trends were however similar to those shown for the PA: Zn molar ratio, with combined use of organic and inorganic fertilizers resulting in the lowest Ca x PA: Zn molar ratio across study areas.

**Table 4.5** Effect of different soil fertility management options on two indicators of Zn bioavailability: (PA, PA: Zn and Ca x PA: Zn)

Treatment	Wedza			Makoni		
	$^{\$}$ PA (mg kg <sup>-1</sup> )	PA : Zn	Ca x PA : Zn	$^{\$}$ PA (mg kg <sup>-1</sup> )	PA : Zn	Ca x PA : Zn
Unfertilized maize (control)	1 755 <sup>a</sup>	125 <sup>b</sup>	4 638	1 690 <sup>a</sup>	130 <sup>b</sup>	6 513
Maize after legume	2 275 <sup>c</sup>	119 <sup>b</sup>	5 891	1 950 <sup>b</sup>	130 <sup>b</sup>	9 893
Maize + cattle manure + NPK	2 210 <sup>b</sup>	105 <sup>a</sup>	4 515	1 950 <sup>b</sup>	115 <sup>a</sup>	6 675
Maize + leaf litter + NPK	2 210 <sup>b</sup>	96 <sup>a</sup>	4 266	1 885 <sup>a</sup>	99 <sup>a</sup>	6 012
Maize + mineral NPK	2080 <sup>b</sup>	130 <sup>b</sup>	5 278	2 210 <sup>c</sup>	158 <sup>c</sup>	9 061
Mean	2 106	115.3	4 918	1 937	126.4	7 631
LSD	187	12.8	1 219	256	16.3	1 722
F test	*	*	ns	*	*	ns

PA = phytic acid; \* means significant treatment differences at  $p < 0.05$ ; means accompanied by same letter within a column are not significantly different; ns = no significant differences ( $P > 0.05$ ).

## **4.6 Discussion**

### ***4.6.1 Nutrient resources and soil fertility management practices commonly used by farmers***

Major soil fertility management domains differentiating crop production by smallholder farmers in this study involved mainly nitrogen-fixing grain legumes, livestock manure, woodland litter and mineral fertilizers. These nutrient resources basically define options known to be available to most of the smallholders in Southern Africa (Mapfumo and Giller, 2001; Mafongoya et al., 2006) and much of sub-Saharan Africa (Gichuru et al., 2003). Results from the study showed that grain legume-maize rotations was the most commonly used management option by farmers across the agro-ecological zones. Over the past decades, smallholder farmers used to grow legumes on small patches of land with little external inputs (Snapp et al., 1998; Mapfumo et al., 2001; Snapp et al., 2010). This study has however indicated that each season, a significant proportion of cropped lands is now allocated to legumes partly due to increased stakeholder partnerships that have yielded contractual arrangements between seed companies and communities for soybean and cowpea production under SOFECSA interventions in the study areas (Kanonge et al., 2009).

The proportion of farmers applying sole mineral fertilizer to maize was relatively high in the two agro-ecological zones possibly due to availability of fertilizers under an input loan scheme promoted by government in the study areas. Farmer innovations that included combined selling of surplus maize to the Grain Marketing Board (GMB), a national input-output marketing agency situated in each district in Zimbabwe, in exchange for mineral fertilizer could also have contributed to the increased proportion of farmers able to apply mineral

fertilizer to staple maize. Among the organic resources available to farmers, cattle manure use in combination with mineral fertilizer was mainly used by resource-endowed farmers, a group defined by their high cattle ownership and relative financial capacity to purchase mineral fertilizers (Mtambanengwe and Mapfumo, 2005). A small proportion of farmers used woodland litter, particularly those living in close proximity to mountains and common natural woodlands, as well as those who have cattle and labour to collect the litter. Apart from labour constraints, there are competing claims for use of tree resources in construction of houses and cattle kraals, and fuel wood among other uses, and this accounts for the reported decline of natural resource pools (Campbell et al., 1998; Woittiez, 2010). Resource constrained farmers who did not own cattle planted maize but failed to purchase mineral fertilizers. Poor yields attained without any fertilization was a clear indication that it is difficult to realize the benefits of ISFM without application of mineral fertilizers.

#### ***4.6.2 Influence of organic nutrient resources on soil Zn, P and Ca status***

Soil samples collected from farmers' fields differed significantly in their available soil Zn, P and Ca despite them belonging to the same textural class. Differences in initial nutrient concentrations of organic resources seemed to strongly influence soil chemical properties as shown by woodland leaf litter treatments having the highest extractable soil Zn concentration. Woodland litter had about six times the amount of Zn measured in cattle manure, suggesting that dominant miombo tree species have high capacity to mobilize soil nutrients in their growth environments and accumulate high levels of Zn in leaves. The tropical savanna woodland (miombo) tree species are known for their potential to scavenge for nutrients from deeper soil horizons (Muller-Samann and Kotshi, 1994; Ryan et al., 2011) and to tightly

recycle major macronutrients including N (Mtambanengwe and Mapfumo, 1999). Upon senescence, their leaves decompose and form humic substances that are important both in the retention of micronutrients in the soil and transportation in soil solution (Geering and Hodgson, 1969). Use of legume-cereal rotations proved a possible avenue for improving extractable soil Zn as indicated by high levels of EDTA Zn. This may be due to the high capacity of legumes to scavenge nutrients from the soil and release back to the soil through dropping of leaves (Cakmak, 2002). However, the EDTA extractable soil Zn values for most of the treatments measured in this study were still below the critical value of  $1.5 \text{ mg kg}^{-1}$  (Dobermann and Fairhurst, 2000) suggesting the soil Zn stocks were inherently too low to support any meaningful accumulation of the nutrient for cropping purposes. These findings strongly highlight the inadequacies of available organic materials to meet cropping demands for soil Zn uptake. There may, therefore, be a need for increased use of Zn-containing mineral fertilizers. The other option would be for farmers to use high input rates for organic nutrient resources but this is unlikely against a background of inherently low soil Zn stocks and general scarcity of organic resources as the natural pools decline.

Differential impact of the soil fertility management practices used farmers on available soil Zn, P and Ca suggests that the three nutrient elements could be among factors critically limiting maize performance and grain quality in the farming systems. Both P and Zn are known to be inherently low in granitic parent materials in Zimbabwe (Grant, 1981; Tagwira, 1991), and results from this study suggests that soil fertility management practices by farmers have a further and strong influence on distribution of these nutrient elements across field and temporal scales. Combined application of organic and inorganic fertilizers, and legume-maize rotations significantly improved availability of Ca and extractable Zn and P. High Ca

concentrations in legume-cereal rotation treatments and cattle manure treatments could be attributed to external application of Ca containing fertilizers to legumes and potential supply of secondary nutrients by cattle manure. Leguminous plants have been particularly found to improve mobilization, recycling and subsequently availability of nutrients including Ca under poor fertile soils (Palm et al., 1997; Cakmak, 2002; Mapfumo and Mtambanengwe, 2004). However, the results in this study suggest that the building of stocks of these soils is insufficient in meeting the demands of cereals making mineral fertilization an important consideration.

#### ***4.6.3 Maize grain yield under different soil fertility management practices***

Maize grain yields following combined application of organic and mineral fertilizers were about two-fold higher than other soil fertility treatment domains regardless of type of organic material. Improved nutrient use efficiencies derived from combined use of organic and mineral (inorganic) nutrient resources have been well quantified (Palm et al., 1997; Chikowo et al., 2010). Organic materials do not only improve a range of soil biological and physical properties, but also directly contribute to SOM build up and supply of secondary (Mg and Ca) and micronutrients such as Zn (Mtambanengwe and Mapfumo, 2009; Masvaya et al., 2010). This positively influences uptake of macro-nutrients such as N and P by the growing plant. Some studies conducted in tropical regions also realized yield benefits of legume-cereal rotations (Giller, 2001). However, in some cases the influence of micronutrient deficiencies is not readily expressed in crop yield reduction. For example, in the current study, there were significant differences in plant available soil Zn, P and Ca, but Zn availability did not significantly influence grain yields.

Zinc availability was unlikely to have an overriding effect in soils inherently deficient in N and P. Availability of P from organic nutrient resources, mainly woodland leaf litter could therefore have been the possible reason for the observed differences in grain yields. In several studies evaluating legume-cereal rotations under smallholder farming systems, cereal yields have often been more than doubled (Waddington and Karigwindi, 2001; Adjei-Nsiah et al., 2008), but there has often been failure to explain the yield benefits solely in terms of N contributions by the legume(s). The influence of micronutrient supply patterns on the yields of subsequent cereals under such rotational studies has largely remained unexplored.

#### ***4.6.4 Effect of soil fertility management practice on maize grain nutrient concentration and Zn uptake***

Overall, maize Zn uptake was significantly improved by combined use of organic nutrient inputs and mineral fertilizer, including legume-based rotations. Notably, grain Zn concentration was higher in maize grown under combined use of woodland leaf litter and inorganic fertilizers than the other soil fertility management treatment domains. Previous studies by Singh et al., (1983) and Rupa et al., (2003) also showed that combined use of organic and inorganic Zn fertilizers could improve Zn concentrations of cereal crops resulting in high mineral content in staple cereal grains. Maize collected from soils grown to legumes in the previous season had higher maize grain Zn concentrations than that grown with mineral fertilizers. In this study, Zn concentration measured in grain legumes were 22 mg kg<sup>-1</sup> in cowpea and 25 mg kg<sup>-1</sup> in soybean (data not shown) and these were higher than concentrations reported in maize. This is most likely because legumes tend to accumulate more Zn in their seeds and leaves due to their higher protein concentrations when compared to cereal grains



(Cakmak et al., 2010a). A review by Cakmak et al., (2010a) support evidence that plants with higher protein concentrations also contain higher Zn concentrations. Increasing supply of N to wheat plants improved Zn and Fe concentrations of both shoot and grain samples (Aciksoz et al., 2011; Kutman et al., 2011). Legumes with high protein concentrations are therefore expected to contain higher Zn concentrations (Welch and Graham, 1999).

It is well-documented that both solubility and mobility of Zn in soils is greatly improved by increasing organic matter content of soils (Marschner, 1993). Significant effect of quality of organic amendments on Zn uptake has also been reported (Balik et al., 2002) and this could account for differences observed among livestock manure and leaf litter amended soils. These results suggest that plant organic materials are major stores for available Zn, and conversely, management processes favouring their exportation may lead to rapid mining. It was however important to note that although farmers' soil fertility management regimes resulted in significant differences in grain Zn concentration, values were still below the recommended concentration levels of 40 mg kg<sup>-1</sup> (Pfeiffer and McClafferty, 2007; Cakmak et al., 2010a) required to combat human Zn malnutrition. Thus the current levels of nutrient inputs and soil fertility management practices by farmers are still inadequate to meet required levels of grain Zn uptake in maize. These findings warrant evaluation of alternative Zn fertilizer sources that could enhance the current role of organic nutrient resources used for soil fertility management by farmers. The maize grain Zn concentration increased with an increase in available soil Zn. Plant Zn uptake is known to be directly proportional to extractable soil Zn concentration (Chang et al., 1983). Gonzalez et al., (2008) also observed a significant positive linear relationship between shoot Zn concentration for navy bean and diethylenetriaminepentaacetic acid (DTPA) extractable soil Zn. The significant positive linear relationship between grain Zn

and EDTA extractable soil Zn found in this study is a clear indication that application of Zn-containing fertilizers can be an assurance for increasing soil Zn and maize grain nutrient concentrations.

#### ***4.6.5 Maize grain indicators of Zn bioavailability as affected by fertility differences***

The PA: Zn molar ratios measured in this study suggest that Zn bioavailability to humans is likely to be low in all treatments but less so in maize grain produced under combined use of organic and inorganic fertilizers and legume-based rotations. Using the critical PA: Zn ratio of <15 as recommended for improved Zn bioavailability (Morris and Ellis, 1989; Hambidge et al., 2008), the results suggest that maize produced under current farmer soil fertility management practices has poor Zn bioavailability. Sole application of mineral fertilizers further increased the PA: Zn molar ratio to unappreciable levels and this could be attributed to relatively increased P uptake. Similar findings were recorded in Sahelian sorghum in Northern Burkina Faso (Traore, 2006).

The Ca x PA: Zn molar ratios measured were also above the critical ratio of 200 which further implied poor bioavailability of Zn in human diets. The nutritional adequacy of dietary Zn depends on both its amount in staple grains and bioavailability in the diet. A PA: Zn molar ratio of >15 has a low Zn absorption level of around 15% compared to a PA: Zn molar ratio of <5, which has an absorption level of around 25% (WHO, 1996). As most PA: Zn molar ratios measured in farmers' fields were above 15, it shows that most soil fertility management practices that are currently being employed by farmers do not have sufficient capacity to favourably regulate the PA: Zn molar ratio, hence rural communities are at high risk of Zn malnutrition. Though unrefined grains have other nutritional benefits, susceptibility to Zn

deficiency in poor communities is worsened by consumption of diets high in unrefined grains and low in animal protein (Nube and Voortman, 2006). Hence, diets should constitute of agronomic fortified grain to suppress the effect of phytic acid on Zn, which is highly concentrated in unrefined grains. Based on this study, fertilization of staple maize with Zn-containing fertilizers, coupled to appropriate use of available organic nutrient resources provides a potential avenue for improving the Zn nutritive value of maize in smallholder farming systems. The nutritional quality and relative dietary contributions of other agricultural produce and food sources consumed by smallholder communities and susceptibility of communities to Zn malnutrition remains largely unknown.

#### **4.7 Conclusions**

The study revealed that the current soil fertility management practices employed by smallholder farmers have a differential impact on soil Zn and P availability, even if they may not obviously influence crop yields and other soil chemical properties such as SOM in the short term. Combined use of organic nutrient resources, such as cattle manure and woodland leaf litter, with mineral fertilizer, as well as legume-based rotations, significantly increased soil Zn status. However, under farmers' current soil fertility management regimes, these nutrient resources can lead to high yields of staple maize, but are inadequate to meet the Zn uptake levels required to eliminate threats of human nutritional deficiencies in the smallholder sector in Zimbabwe. Although farmer soil fertility management practices have shown a significant influence on soil Zn, the overall problem is in inherently low stocks of Zn and P in soils. Current fertilizer formulations used on maize tend to further reduce Zn bioavailability due to relatively high P and Ca concentrations in the grain. It is therefore imperative that Zn-

containing mineral fertilizers are systematically used in order to enhance the potential role of farmers' current soil fertility management practices in addressing Zn malnutrition among the resource-poor communities. Further empirical research on diversity and nutritional quality attributes of common agricultural produce and alternative food sources contributing to staple diets of smallholder communities is warranted.

## Chapter 5

### Effects of different zinc fertilizer formulations and methods of application on maize productivity and grain quality<sup>§</sup>

#### 5.1 Abstract

Fertilization of staple cereal crops in smallholder farming systems of sub-Saharan Africa has mostly focused on supply of nitrogen (N), phosphorus (P) and potassium (K), despite the widespread deficiency of micronutrients that include zinc (Zn). On granitic sandy soils occurring widely in Southern Africa, Zn deficiency limits crop productivity and as a result, the nutritional value of food crops originating from such soils is compromised. A study was conducted between 2008 and 2010 on smallholder farms in Wedza and Makoni districts of eastern Zimbabwe to evaluate effect of different Zn fertilizer formulations on maize (*Zea mays* L.) yields and subsequently grain Zn concentration. Application of basal and foliar Zn fertilizers, solely or in combination, increased maize grain yields, out yielding the non-Zn treatment by up to 62%. Significant differences in maize grain Zn uptake ( $p < 0.01$ ) were observed during each of the two seasons, with highest uptake of  $\sim 114 \text{ g Zn ha}^{-1}$  attained after application of a basal NPK fertilizer containing 1% Zn. Ear leaf samples had Zn concentrations within the range of 16 - 51  $\text{mg kg}^{-1}$  and 21.6 - 78.0  $\text{mg kg}^{-1}$  in 1<sup>st</sup> and 2<sup>nd</sup> season respectively, an increase of up to 192% against the control. The Zn concentrations measured in maize grain during the 2008/09 and 2009/10 seasons ranged from 14.3 - 30.3  $\text{mg kg}^{-1}$  and 18.7 - 39.0  $\text{mg kg}^{-1}$  respectively, with the highest concentrations realized after co-application of basal and foliar Zn fertilizers. There was a significant and positive linear relationship between EDTA-extractable soil Zn and maize grain Zn concentration ( $R^2 > 0.80$ ). The results indicated that, irrespective of method of application, Zn fertilizers improved maize productivity and grain Zn concentration, potentially meeting the required threshold for significant influence on human nutrition.

<sup>§</sup>Data in this Chapter were presented as: Grace M. Manzeke, Regis Chikowo, Florence Mtambanengwe, Ismail Cakmak, Paul Mapfumo. 2011. Evaluating the Potential of Zinc-Containing Fertilizers for Improved Production and Zinc Nutrition of Maize Grain in Zimbabwe. Abstract presented at the 3<sup>rd</sup> International Zinc Symposium on "Improving crop production and human health". Hyderabad, India, 10 - 14 October 2011.

#### 5.2 Introduction

Zinc concentrations in soils commonly range from 10 - 300  $\text{mg kg}^{-1}$  (Alloway, 2004). However, the concentrations in sandy soils found in communal areas of Zimbabwe rarely exceed 48  $\text{mg Zn kg}^{-1}$  (Tagwira, 1991). Nearly 50% of cereal growing areas in the world have

soils with low plant available Zn (Graham and Welch, 1996; Cakmak, 2002) resulting in Zn concentrations in cereal grains of as little as 5 – 12 mg kg<sup>-1</sup> (Erdal et al., 2002), against a requirement of 40 – 60 mg kg<sup>-1</sup> (Kalayci et al., 1999; Pfeiffer and McClafferty, 2007). Cereal crops are a major source of proteins and minerals in developing countries. For example, 50% of daily calorie intake in central and Western Asia is provided from wheat, and tends to increase to 70% in rural areas (Cakmak, 2008). Zinc concentrations of 20 – 35 mg kg<sup>-1</sup> recorded in wheat (Rengel et al., 1999) are too low to meet daily human requirements of 1.1 – 11.2 mg day<sup>-1</sup> in children and 3.0 – 19.0 mg day<sup>-1</sup> in adults (WHO, 2002). The National Research Council of the United States of America (1989) also recommends a dietary allowance for Zn of about 15 mg day<sup>-1</sup>.

For a measurable biological impact on human health, cereal grain Zn concentrations will need to increase by 10 mg kg<sup>-1</sup> assuming a 400 g per day intake for adults in countries where cereals are staple and used to make foods such as chapatti (from wheat) in India (Pfeiffer and McClafferty 2007; [www.harvestplus.org](http://www.harvestplus.org)) and sadza (from maize) in Zimbabwe. However, not much literature is available on Zn concentrations in staple cereals of Africa. In most countries including Zimbabwe, a number of studies have been conducted on the role of soil and foliar applied Zn fertilizers in correcting deficiency of the nutrient and increasing plant growth and yield (Martens and Westermann, 1991; Tagwira, 1991; Rengel et al., 1999). Fertilizer studies focusing specifically on improving Zn concentration of cereal grains for enhanced nutrition are however very rare.

There are several ways through which Zn deficiency in humans can be addressed. Breeding and transgenic approaches are powerful and sustainable strategies in biofortification of cereal

crops with Zn. Regrettably, one of the limitations of breeding and transgenic approaches is that they are long term processes that require a series of activities and huge resource investments. It is also not certain that these strategies will work after long term efforts. Breeding involves identification of useful genetic variation and most promising parents, long term crossing and backcrossing activities, stability of target traits (in this case high grain Zn concentrations) across different environments with variable soil and climatic conditions and adaptation of newly developed biofortified genotypes (Cakmak 2008). Major cereal growing areas are characterised by adverse soil chemical properties which could inhibit the capacity of the newly developed cultivar to take up adequate amounts of Zn from the soil to address human micronutrient deficiencies.

Food fortification has been found effective in improving nutritional attributes but faces challenges related to social acceptance and high costs. For example, to eliminate micronutrient deficiencies in a nation of 50 million affected people using a food fortification program will require at least US\$25 million yr<sup>-1</sup> (Bouis, 2003). Supplementation works well in combination with the right nutrients but is often not recommended for children under the age of 12 years, who unfortunately happen to be more prone to Zn malnutrition after weaning. Agronomic biofortification might be a promising suitable approach in improving grain Zn concentrations and address human micronutrients nutrition (Cakmak, 2008). This chapter presents findings from a study conducted to explore opportunities for use of Zn fertilizers to improve the nutritional quality of staple maize in Zimbabwe smallholder areas.

## **5.3 Materials and methods**

### ***5.3.1 Selection and establishment of field sites***

On-farm researcher - managed experiments were established in Wedza and Makoni smallholder farming areas. Selection of fields in each area was based on a preliminary characterization of farmers' fields for soil Zn status, conducted jointly with the help of agriculture extension workers (AEWs') and farmers. Soil samples were collected from the farmers' fields to a depth of 0 – 20 cm using an auger during October 2008 before the cropping season. The soils were characterized for various physico-chemical properties which included texture, pH and Zn. Fields with soils falling in the sand to loamy sand textural class and exhibiting low EDTA-extractable soil Zn of  $<1.5 \text{ mg kg}^{-1}$  were then selected for experimentation.

### ***5.3.2 Fertilizer treatments and crop planting***

An ox-drawn plough was used to prepare the selected fields. Twelve fertilizer treatments were evaluated on plots measuring  $3.6 \times 4 \text{ m}^2$ . The experiment was laid out in a randomized complete block design (RCBD) with six replicates. The experimental design was provided and implemented under the broad framework of the Harvest Plus Zinc project of Sabanci University in Turkey. Basal PKS (32%  $\text{P}_2\text{O}_5$ : 14%  $\text{K}_2\text{O}$ : 4% S) and Zn containing fertilizers were broadcast at  $26 \text{ kg P ha}^{-1}$  and  $11 \text{ kg Zn ha}^{-1}$  respectively, prior to maize planting and disced in for thorough mixing. The details of treatments used are given in Table 5.1, while description of fertilizer type and composition is given in Table 5.2. In all treatments, PKS was applied to balance P requirements. Maize cultivar, SC 513, was used as test crop. Planting of



this early to medium maturity cultivar was done with the onset of the rains in November 2008. A crop spacing of 0.9 m x 0.3 m inter-row and intra-row, respectively was used giving a population of ~37 000 plants ha<sup>-1</sup>. Ammonium nitrate (AN) was applied as a top dressing fertilizer at a rate of 120 kg N ha<sup>-1</sup> at least 2 cm from the plant. The fertilizer was applied in three splits, 30% at 2 weeks after emergence (WAE), 40% at 6 WAE and 30% at silking. A control treatment was included where no Zn-containing fertilizer was applied.

**Table 5.1** Treatments used to evaluate the effect of different Zn fertilizer formulations on maize productivity and maize yielding components.

Treatment	Soil fertilizers		Foliar fertilizer
	Macronutrient fertilizers	Zinc fertilizers	
1	<sup>1</sup> PKS + <sup>2</sup> AN (Control)	Not applied	Not applied
2	PKS + AN	<sup>3</sup> Soil ZnO	Not applied
3	PKS + AN	Not applied	<sup>4</sup> ZnSO <sub>4</sub> .7H <sub>2</sub> O
4	PKS + AN	Soil ZnO	ZnSO <sub>4</sub> .7H <sub>2</sub> O
5	PKS + AN	Not applied	OMEX Type 1
6	PKS + AN	Not applied	OMEX Type 2
7	AN	Compound Z	Not applied
8	PKS + AN	<sup>5</sup> MESZ – Zn	Not applied
9	PKS + AN	Compound Z	Not applied
10	PKS + AN	Compound Z	ZnSO <sub>4</sub> .7H <sub>2</sub> O
11	PKS + AN	MESZ - Zn	ZnSO <sub>4</sub> .7H <sub>2</sub> O
12	PKS + AN	Compound Z + Soil ZnO	Not applied

<sup>1</sup>PKS = Phosphorus-Potassium-Sulphur; <sup>2</sup>AN = Ammonium nitrate; <sup>3</sup>ZnO = Zinc oxide; <sup>4</sup>ZnSO<sub>4</sub>.7H<sub>2</sub>O = heptahydrate Zinc sulphate; <sup>5</sup>MESZ = Micro Essential with Sulphur and Zinc.

**Table 5.2** Composition of the different fertilizers used to investigate effect of Zn on maize productivity and nutritional quality

<b>Form (Compound)</b>	<b>Composition (%)</b>	<b>Method of application/ Rate ha<sup>-1</sup></b>
AN	34.5 N	Top dressing at 120 kg N ha <sup>-1</sup>
PKS	32 P <sub>2</sub> O <sub>5</sub> *, 16 K <sub>2</sub> O*, 5 S	Basal applied at 26 kg P ha <sup>-1</sup>
ZnO	78 Zn	Basal applied at 11 kg Zn ha <sup>-1</sup>
MESZ	12 NH <sub>3</sub> N, 41.5 P <sub>2</sub> O <sub>5</sub> , 5.7 S, 1 Zn	Basal applied at 11 kg Zn ha <sup>-1</sup>
Compound Z	7 N, 14 P <sub>2</sub> O <sub>5</sub> , 7 K <sub>2</sub> O, 1 Zn	Basal applied at 11 kg Zn ha <sup>-1</sup>
ZnSO <sub>4</sub> ·7H <sub>2</sub> O	22 Zn	Foliar applied at 25 kg Zn ha <sup>-1</sup>
OMEX Type 1	0 N, 53 P <sub>2</sub> O <sub>5</sub> , 23 K <sub>2</sub> O, 6.2 Zn	Foliar applied at 25 kg Zn ha <sup>-1</sup>
OMEX Type 2	12 N, 0 P, 0 K, 27 Zn	Foliar applied at 25 kg Zn ha <sup>-1</sup>

\*To get actual P and K in P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, multiply the composition percentage by 0.44 and 0.83, respectively.

### **5.3.3 Agronomic management of field experiments**

Weeding was done manually using hoes, and effective control of weeds was achieved throughout the growing seasons. Maize stalk borer was also effectively controlled through the application of thionex granules (2.5% carbaryl) at a rate of 3–4 kg ha<sup>-1</sup> at 6 WAE..

### **5.3.4 Plant sampling and analysis for Zn uptake**

At tasselling, 10 ear leaf maize samples were collected from each plot before application of foliar fertilizers, and placed in well labelled khaki packs for storage. The samples were air dried and later oven dried at 60 °C to a constant weight. Samples were ground using a Thomas Wiley Model 4 stainless steel mill and put in polythene containers before laboratory analysis. Care was taken not to contaminate the samples with any Zn containing material. During the first year of fertilizer application, Zn concentration in ear-leaf samples was only measured in Wedza. No ear-leaf samples were collected in Makoni because the field was water logged due to severe rains of ~300 mm received during the month of January 2009. Total rainfall received

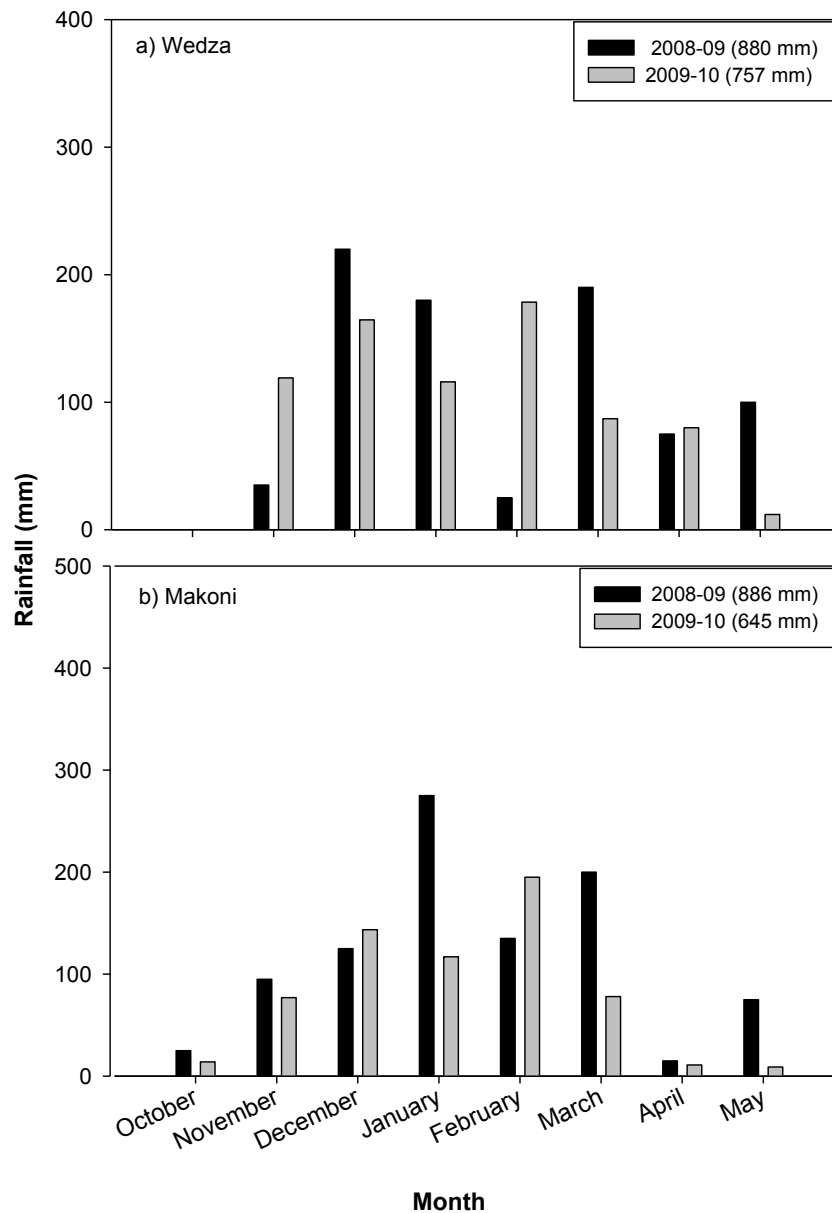
during the 2008/09 and 2009/10 cropping seasons in Wedza and Makoni is presented in Figure 5.1.

### ***5.3.5 Foliar fertilizer application and grain sampling***

Foliar Zn fertilizer solutions were prepared to achieve a supply rate of 0.3% Zn (25 kg ha<sup>-1</sup> of Zn fertilizer) and were applied in respective plots, first at tasselling and then a week after silking. A Farmate NS-16 knap sack sprayer was used to apply the liquid fertilizers and application done until the leaves were dripping wet. At physiological maturity, maize cob samples were collected from a net plot of 1.8 x 2.8 m<sup>2</sup>. Cobs were air-dried and shelled manually. Maize grain yield was then quantified at 12.5% moisture content. Grain samples were then ground in a stainless steel mill to avoid contamination. Processed grain was analysed for N, P, Ca and Zn concentrations as described in Chapter 3, Section 3.4.4. Bioavailability of Zn was determined by calculating the PA:Zn and Ca x PA:Zn molar ratios in the grain.

### ***5.3.6 Assessment of Zn residual effects***

During the 2<sup>nd</sup> growing season in 2009/10, planting was done on the 10<sup>th</sup> of November and no basal Zn fertilizers were applied; only N, P, K and foliar Zn fertilizers were applied to the respective treatments as highlighted earlier in Table 5.1. This was because residual effects of basal Zn fertilizers were anticipated to persist for 3 - 4 seasons (Tanner, 1975; Tagwira 1991) and the crop would still benefit from residual fertility (Martens and Westermann, 1991). Foliar sprays can be applied every season to benefit the fruit under development (Cakmak, 2008). Soil samples were collected at the end of each cropping season from 5 randomly selected points in each plot to a depth of 0 – 20 cm and analysed for plant available soil Zn.



**Figure 5.1** Rainfall received during the 2008/09 and 2009/10 cropping seasons in a) Wedza and b) Makoni.

#### 5.4 Statistical analyses

Effects of different Zn fertilizer formulations on maize grain yield, grain nutritional value and soil chemical properties were examined by analysis of variance (ANOVA) using GENSTAT version 13 statistical package (Lawes Agricultural Trust, Rothamsted Experimental Station,

U.K). The honestly significant difference (HSD) test, also referred to as the Tukey's test, was used to separate treatment means at  $P = 0.05$ . Relationship between grain Zn concentration and ear-leaf and extractable soil Zn was explored through simple linear regression using Sigma Plot version 10.0 (SPSS, Chicago, IL. USA).

## 5.5 Results

### 5.5.1 Initial characterization of farmers' fields

Soils from both Wedza and Makoni were in the sand to loamy sand textural class, containing 95 and 80% sand, respectively (Table 5.3). The soils had very low mineral N and available P with the lowest values of  $18 \text{ mg N kg}^{-1}$  and  $4.0 \text{ mg P kg}^{-1}$  measured in Wedza. Organic C as high as 0.7%, was measured from the site in Makoni. Soils from both areas were generally acidic as depicted by low pH values of around 4.5 (Table 5.3). At both study sites, soils were deficient in Zn with values below  $1.5 \text{ mg kg}^{-1}$ . The Ca to Mg ratio was around 1.5.

**Table 5.3** Physical and chemical characteristics of soils collected from two field sites on which the Zn trials were established in Zimbabwe

Parameter	Site	
	Wedza District	Makoni District
Clay (%)	5 (0.1)	8 (0.6)
Sand (%)	95 (0.6)	80 (1)
Textural class	Sand	Loamy sand
Total N (%)	0.03 (0.006)	0.06 (0.003)
Mineral N ( $\text{mg kg}^{-1}$ ) <sup>a</sup>	18 (1)	28 (1.3)
Available P ( $\text{mg kg}^{-1}$ ) <sup>b</sup>	4.0 (0.3)	8.4 (0.2)
Organic carbon (%)	0.31 (0.08)	0.70 (0.06)
pH (0.01 M $\text{CaCl}_2$ )	4.5 (0.11)	4.4 (0.13)
Available Zinc ( $\text{mg kg}^{-1}$ )	1.35 (0.1)	0.60 (0.5)
Ca ( $\text{cmol}_c\text{kg}^{-1}$ )	0.9 (0.01)	1.6 (0.02)
Mg ( $\text{cmol}_c\text{kg}^{-1}$ )	0.6 (0.01)	1.1 (0.04)
K ( $\text{cmol}_c\text{kg}^{-1}$ )	0.1 (0.001)	0.3 (0.004)

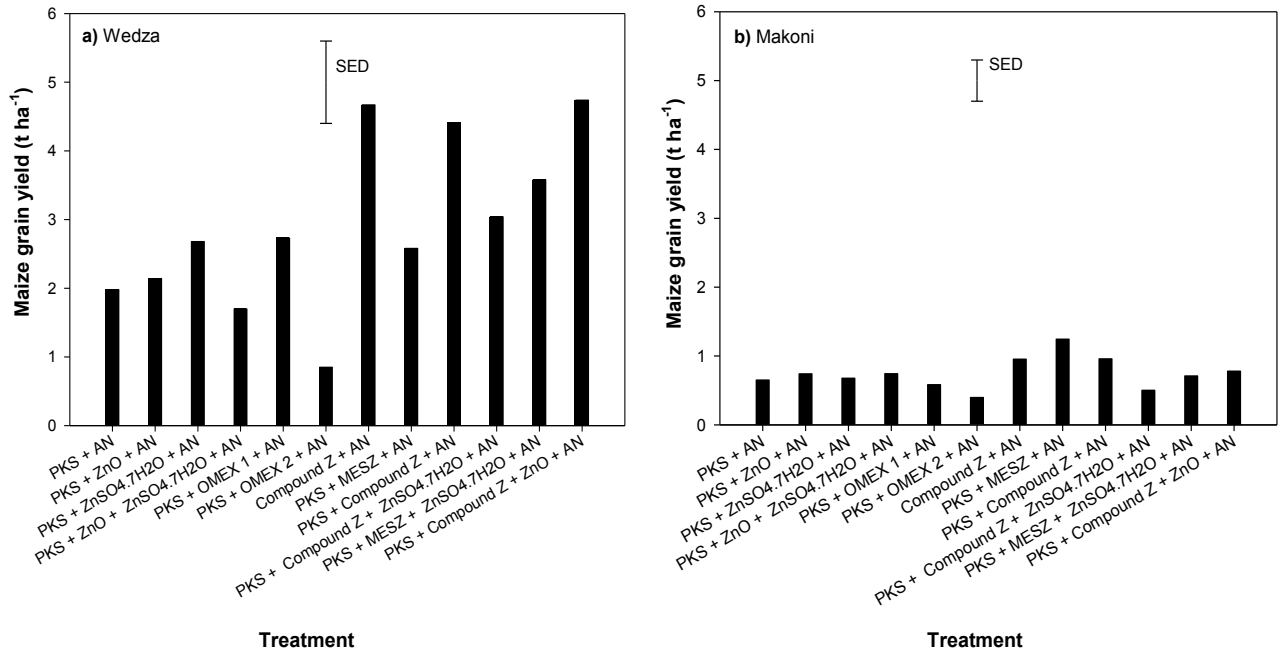
Makoni = Chikodzo farm; Wedza = Muzondo farm; <sup>a</sup>Mineralizable N after two weeks of anaerobic incubation; <sup>b</sup>Available P measured using the Olsen method. Values in parentheses denote standard errors of means.

### ***5.5.2 Influence of different zinc fertilizers on maize grain yield***

In both study areas, significant maize grain yield differences were observed among treatments ( $p < 0.05$ ) during the 2008/09 cropping season. In Wedza, maize grain yields ranged from 0.9 – 4.7 t ha<sup>-1</sup> and highest yields were attained after application of basal Compound Z and ZnO + AN (Figure 5.2a). In Makoni, maize grain yields ranged from 0.5 – 1.2 t ha<sup>-1</sup> (Figure 5.2b), with basal compound Z producing the highest yields. In both Wedza and Makoni, lowest maize grain yields were obtained from foliar OMEX 2 Zn although it contained 27% Zn. This seems to suggest that high concentration of Zn in this formulation had a reducing yield effect on maize due to foliage burning.

Treatments which received starter N at planting produced higher grain yields than under PKS + Zn fertilizer only indicating that the soils were N limited. However, the relatively good response of maize to a combination of PKS and Compound Z further suggests that there are high P benefits when starter N was added. Application of foliar Zn fertilizers either solely or in combination with basal Zn fertilizers, out-yielded the control treatment by up to 62% in Wedza and 46% in Makoni.

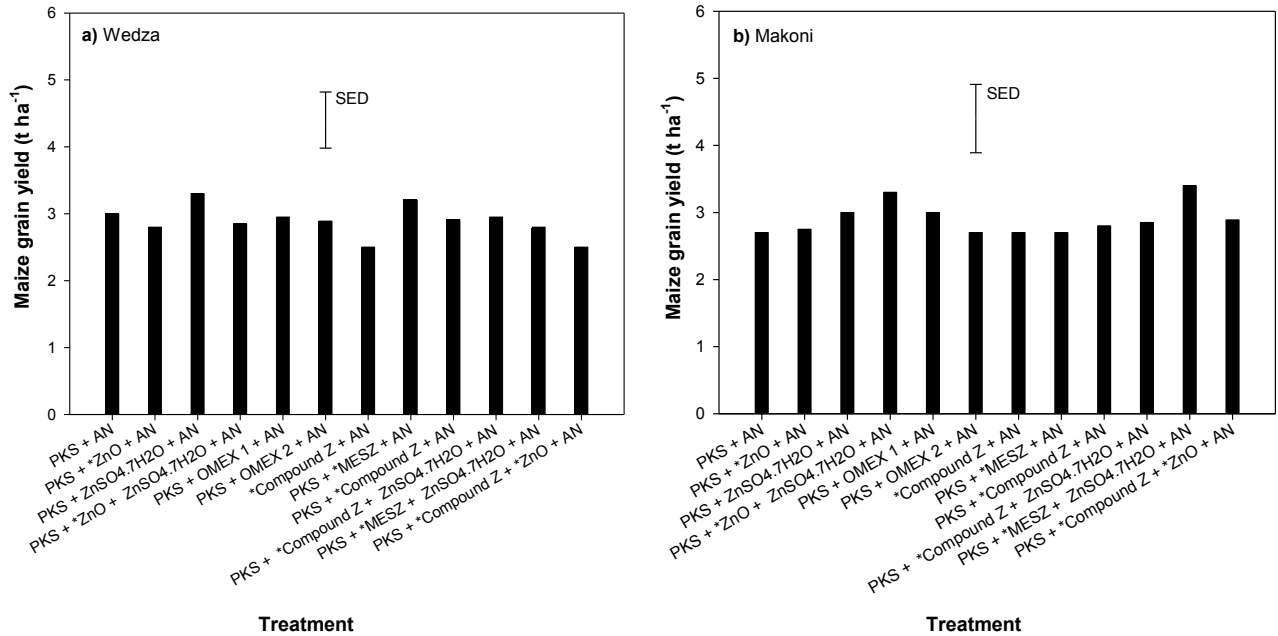
Relatively depressed yields in Makoni were attributed to excessive rains received in the area during the early part of the 2008/09 cropping season. Approximately 300 mm were received during the month of January alone, resulting in severe water logging and possibly N leaching.



**Figure 5.2** Maize grain yields obtained during the 2008/09 season after application of different zinc containing fertilizers. SED—Standard error of differences between means.

During the 2nd growing season of 2009/10, residual effects of different basal Zn fertilizer formulations did not significantly influence maize yields ( $p > 0.05$ ). Maize grain yields ranged from 2.5 – 3.3 t ha<sup>-1</sup> and 2.7 – 3.4 t ha<sup>-1</sup> in Wedza and Makoni (Figure 5.3a and 5.3b), respectively.

Maize produced under residual basal and foliar Zn fertilizers had higher grain yields compared with the other treatments. The non-Zn treatment was not significantly different from either sole foliar or residual basal Zn treatments.



**Figure 5.3** Maize grain yields obtained in the second season of 2009/10 following residual basal fertility and application of foliar Zn fertilizers. \* indicate treatments where residual fertility was assumed.

### 5.5.3 Contribution of different Zn fertilizers to maize ear leaf N, P and Zn concentrations

Significantly different ( $P < 0.05$ ) maize ear leaf Zn concentrations were observed among treatments during the 2008/09 cropping season. Ear leaf samples collected from basal Zn fertilizer treatments consistently resulted in the highest Zn concentrations. Maize ear-leaf concentrations ranged between 16 and 51 mg Zn kg<sup>-1</sup> (Table 5.4), up to 183% increase over the control. Treatments receiving Compound Z and ZnO had the highest Zn concentration. Combined application of basal and foliar Zn fertilizers gave an increase in ear leaf Zn concentration of between 6 – 58% over sole application of foliar Zn fertilizer.

Leaf P concentration was significantly influenced by treatments during the first season at the Wedza site and ranged from 0.24 – 0.33% (Table 5.4). Lowest ear-leaf P concentrations were attained in treatment which recorded the highest Zn concentration except for maize which



received OMEX 2. Significant differences in maize ear-leaf N concentrations were measured with concentrations ranging from 1.46 – 1.84% (Table 5.4).

**Table 5.4** Maize ear leaf N, P and Zn concentration as affected by different fertilizers in Wedza, Zimbabwe during the 2008/09 cropping season

Treatment	Ear leaf Zn concentration (mg kg <sup>-1</sup> )		
	N (%)	P (%)	Zn (mg kg <sup>-1</sup> )
PKS + AN (control)	1.53 <sup>ab</sup>	0.44 <sup>b</sup>	18 <sup>a</sup>
PKS + *ZnO+ AN	1.63 <sup>ab</sup>	0.39 <sup>ab</sup>	29 <sup>b</sup>
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.60 <sup>ab</sup>	0.40 <sup>ab</sup>	18 <sup>a</sup>
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.61 <sup>ab</sup>	0.37 <sup>a</sup>	31 <sup>b</sup>
PKS + §OMEX Type 1+ AN	1.64 <sup>ab</sup>	0.40 <sup>ab</sup>	16 <sup>a</sup>
PKS + §OMEX Type 2+ AN	1.84 <sup>b</sup>	0.37 <sup>a</sup>	17 <sup>a</sup>
*Compound Z + AN	1.46 <sup>a</sup>	0.38 <sup>ab</sup>	29 <sup>b</sup>
PKS + *MESZ + AN	1.59 <sup>ab</sup>	0.42 <sup>b</sup>	20 <sup>ab</sup>
PKS + *Compound Z+ AN	1.51 <sup>ab</sup>	0.41 <sup>b</sup>	24 <sup>ab</sup>
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.55 <sup>ab</sup>	0.41 <sup>b</sup>	25 <sup>ab</sup>
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.55 <sup>ab</sup>	0.41 <sup>b</sup>	19 <sup>ab</sup>
PKS + *Compound Z + *ZnO+ AN	1.49 <sup>a</sup>	0.37 <sup>a</sup>	51 <sup>c</sup>
SED	0.17 <sup>**</sup>	0.02 <sup>***</sup>	4.85 <sup>**</sup>
Mean	1.58	0.40	24.9
C.V (%)	11.5	9.1	14.4

\* means Zn source was basal applied. § means Zn source was foliar applied. \*\* = treatment effect significant at P < 0.05; \*\*\* = treatment effect significant at P < 0.01. Means followed by the same letter are not significantly different at P<0.01 and 0.05. SED-standard error of differences of means.

#### 5.5.4 Effect of residual fertility on ear leaf Zn and P

When residual effects were tested at each site during the 2009/10 cropping season, there were significant differences in ear leaf Zn concentration among treatments. Zinc concentrations for maize ear-leaf ranged from 20 - 78 mg kg<sup>-1</sup> and 21.6 – 51.4 mg kg<sup>-1</sup> in Wedza and Makoni, respectively (Table 5.5). The highest ear-leaf Zn concentration of 78.0 mg kg<sup>-1</sup> in Wedza and 51.4 mg kg<sup>-1</sup> in Makoni were attained following combined application of ZnO and ZnSO<sub>4</sub>.7H<sub>2</sub>O. Relatively low concentrations in Makoni could have been due to leaching under

excessive rainfall during season of fertilizer application (2008/09). Sole application of foliar  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  and OMEX 1 was the next best treatment in relation to ear-leaf nutrient concentration possibly due to residual fertility effects. There were mixed responses among the other treatments with some significantly higher than the non-fertilized control.

In general, maize ear-leaf P concentrations were within a narrow range of 0.39 – 0.46% in Wedza and 0.18 – 0.22% in Makoni (Table 5.5). In Wedza, P concentrations in the second year were higher than those measured during the 1<sup>st</sup> growing season. Ear leaf N concentration was not determined during the 2009/10 cropping season for both sites.

#### ***5.5.5 Ear leaf aluminum and iron concentrations as affected by application of Zn- based fertilizers***

Ear leaf aluminum (Al) and Fe concentrations of up to 140 mg kg<sup>-1</sup> and 126 mg kg<sup>-1</sup> were recorded in Wedza during the 2008/09 season (data not shown). However, water logging experienced on site in Makoni during the 2008/09 growing season resulted in relatively higher maize Al and Fe ear-leaf concentrations of 3 299 mg kg<sup>-1</sup> and 2 039 mg kg<sup>-1</sup> respectively against concentrations of 94 mg kg<sup>-1</sup> (Al) and 146 mg kg<sup>-1</sup> (Fe) attained in Wedza in the 2009/10 season. Common to both cropping seasons and study sites, application of different Zn fertilizer formulations did not result in significant differences in Al and Fe ( $P > 0.05$ ).

**Table 5.5** Effect of different Zn fertilizer treatments on leaf P and Zn concentration of maize grown under smallholder farmer management in Wedza and Makoni districts, Zimbabwe

Treatment	Wedza		Makoni	
	P	Zn	P	Zn
	%	mg kg <sup>-1</sup>	%	mg kg <sup>-1</sup>
PKS + AN (control)	0.45	20 <sup>a</sup>	0.41	21.6 <sup>a</sup>
PKS + *ZnO+ AN	0.43	37 <sup>b</sup>	0.41	26.7 <sup>ab</sup>
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	0.42	47 <sup>bc</sup>	0.38	30.2 <sup>b</sup>
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	0.39	78 <sup>d</sup>	0.37	51.4 <sup>c</sup>
PKS + §OMEX Type 1+ AN	0.45	59 <sup>c</sup>	0.41	44.4 <sup>c</sup>
PKS + §OMEX Type 2+ AN	0.43	36 <sup>b</sup>	0.40	22.5 <sup>a</sup>
*Compound Z + AN	0.42	28 <sup>ab</sup>	0.48	22.7 <sup>a</sup>
PKS + *MESZ + AN	0.46	30 <sup>ab</sup>	0.45	23.1 <sup>ab</sup>
PKS + *Compound Z+ AN	0.44	27 <sup>ab</sup>	0.44	23.4 <sup>ab</sup>
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	0.42	39 <sup>b</sup>	0.41	25.3 <sup>ab</sup>
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	0.43	37 <sup>b</sup>	0.45	23.5 <sup>ab</sup>
PKS + *Compound Z + *ZnO+ AN	0.44	38 <sup>b</sup>	0.49	31.6 <sup>b</sup>
SED	0.024 <sup>ns</sup>	7.5 <sup>**</sup>	0.04 <sup>ns</sup>	3.85 <sup>**</sup>
Mean	0.43	39.7	0.43	28.9
C.V (%)	9.5	14.4	16.4	13.7

\* means Zn source was assumed to be residual fertility. § means Zn source was foliar applied. \*\* = treatment effect significant at P < 0.05. Within a column, homogeneous groups are denoted by the same letter. ns- treatment means not significantly different at P<0.05.

### 5.5.6 Influence of basal and foliar fertilization on maize grain Zn enrichment

Application of Zn-based fertilizers significantly ( $P < 0.01$ ) and ( $P < 0.05$ ) increased the concentration of Zn in maize grain at both sites in each of the seasons (Table 5.6). In Wedza, maize grain Zn concentrations ranged from 16.0 mg kg<sup>-1</sup> to 30 mg kg<sup>-1</sup> during the 2008/09 season and 18-39 mg kg<sup>-1</sup> during the 2009/10 season. In Makoni, grain Zn concentrations ranged from 14-21 mg kg<sup>-1</sup> and 19-31 mg kg<sup>-1</sup>. Combined use of soil ZnO and foliar ZnSO<sub>4</sub>.7H<sub>2</sub>O resulted in the highest Zn concentrations, outperforming the non-Zn treatment by 47% during the 2008/09 season.

**Table 5.6** Maize grain Zn concentrations as affected by different foliar and basal fertilizer formulations applied on smallholder farms in Zimbabwe

Treatment	Grain Zn concentration (mg kg <sup>-1</sup> )			
	2008/09		2009/10	
	Wedza	Makoni	Wedza	Makoni
PKS + AN (control)	16 <sup>a</sup>	15.7 <sup>ab</sup>	18 <sup>a</sup>	18.7 <sup>a</sup>
PKS + *ZnO+ AN	22 <sup>b</sup>	20.1 <sup>b</sup>	28 <sup>bc</sup>	24.9 <sup>b</sup>
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	27 <sup>cd</sup>	15.5 <sup>ab</sup>	36 <sup>de</sup>	27.7 <sup>bc</sup>
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	30 <sup>d</sup>	20.5 <sup>b</sup>	39 <sup>e</sup>	30.6 <sup>c</sup>
PKS + §OMEX Type 1+ AN	24 <sup>bc</sup>	16.0 <sup>ab</sup>	32 <sup>cd</sup>	20.3 <sup>ab</sup>
PKS + §OMEX Type 2+ AN	25 <sup>c</sup>	15.7 <sup>ab</sup>	35 <sup>de</sup>	24.1 <sup>b</sup>
*Compound Z + AN	18 <sup>a</sup>	15.2 <sup>a</sup>	24 <sup>b</sup>	20.5 <sup>ab</sup>
PKS + *MESZ + AN	18 <sup>a</sup>	17.0 <sup>ab</sup>	25 <sup>bc</sup>	20.3 <sup>ab</sup>
PKS + *Compound Z+ AN	18 <sup>a</sup>	14.4 <sup>a</sup>	24 <sup>b</sup>	21.5 <sup>ab</sup>
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	29 <sup>d</sup>	14.3 <sup>a</sup>	34 <sup>d</sup>	24.9 <sup>b</sup>
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	26 <sup>c</sup>	16.4 <sup>ab</sup>	32 <sup>cd</sup>	25.5 <sup>b</sup>
PKS + *Compound Z + *ZnO+ AN	24 <sup>bc</sup>	18.8 <sup>b</sup>	29 <sup>c</sup>	24.4 <sup>b</sup>
SED	1.4 <sup>***</sup>	1.8 <sup>**</sup>	2.2 <sup>**</sup>	2.0 <sup>**</sup>
Mean	23.2	16.6	29.7	23.6
CV (%)	10.6	7.9	7.1	15.0

\* means Zn source was basal applied. § means Zn source was foliar applied. <sup>1</sup> means residual basal fertility was assumed. \*\* = treatment effect significant at  $P < 0.05$ ; \*\*\* = treatment effect significant at  $P < 0.01$ . Homogeneous groups are denoted by the same letter.

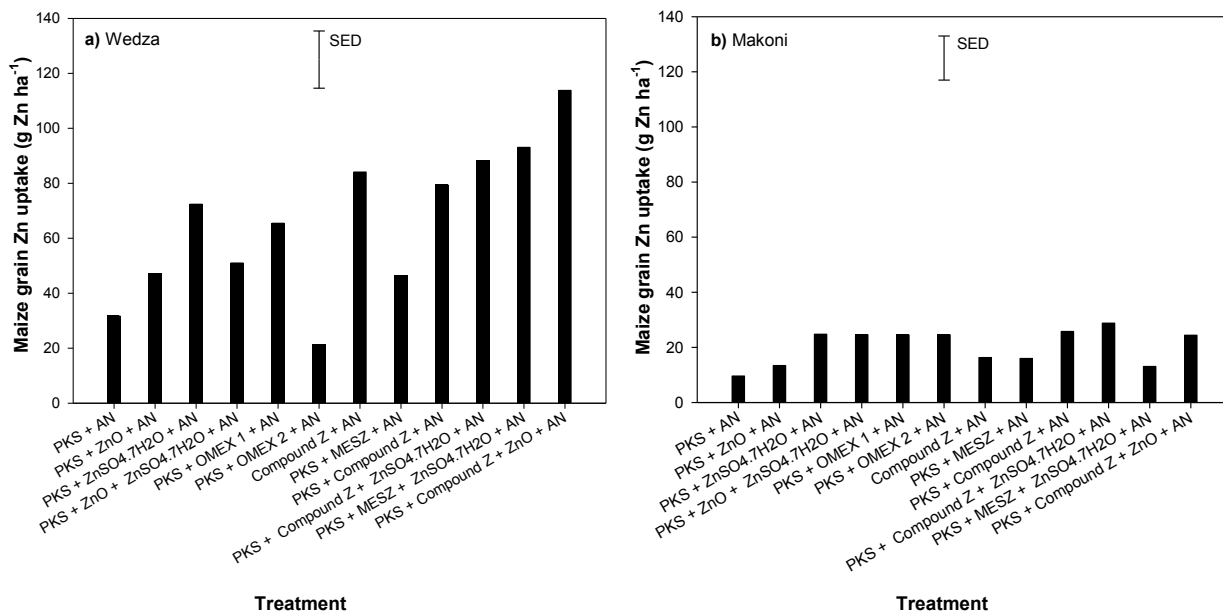
During the 2009/10 cropping season, the same treatment super ceded the control by 117% (Table 5.6). Sole application of either basal or foliar Zn fertilizers significantly superseded the non-Zn treatment by up to 69% and 100% during the 1<sup>st</sup> and 2<sup>nd</sup> cropping seasons, respectively. A 13% and 19% increase in grain Zn concentration measured during the 2<sup>nd</sup> cropping season in Wedza and Makoni, respectively in the non Zn treatment (Table 5.6) could be an indication of the soil's capacity to supply a small amount of Zn. During the 2009/10 cropping season, residual Zn effects resulted in up to 27% increase in grain Zn concentration implying basal Zn fertilizers can persist for over one season.

#### ***5.5.7 Maize grain Zn uptake and relationship between ear-leaf and grain Zn concentration***

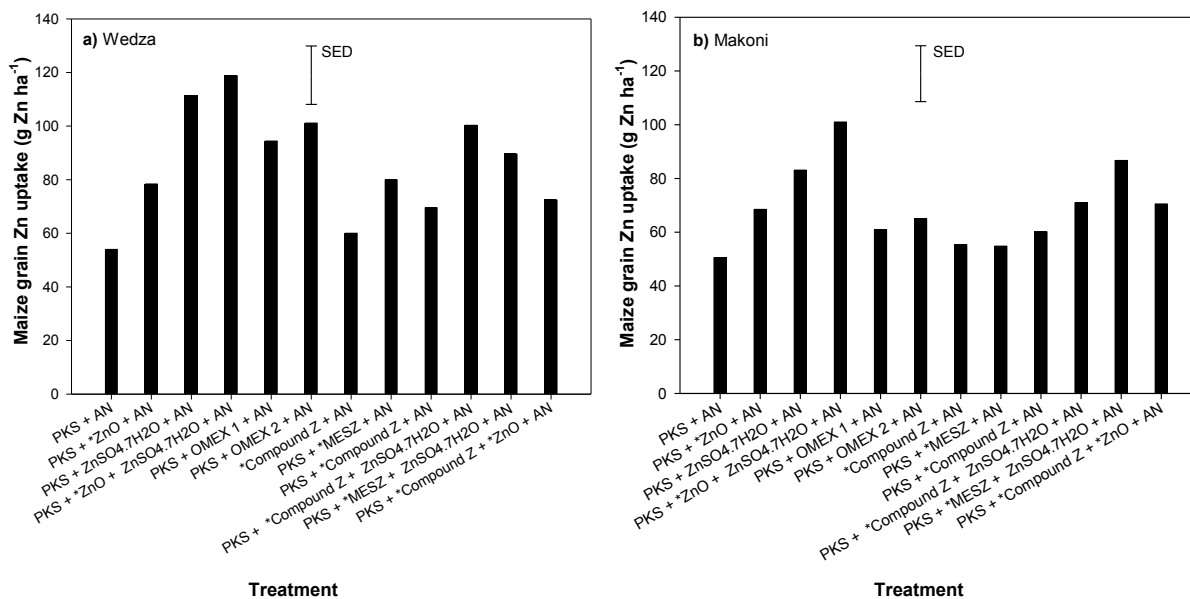
In both areas, significant differences in grain Zn uptake during both cropping seasons ( $P < 0.05$ ) were observed. During the 2008/09 season, maize grain Zn uptake ranged from 21.1 – 113.8 g ha<sup>-1</sup> and 9.6 – 28.8 g ha<sup>-1</sup> in Wedza and Makoni, respectively (Figure 5.4a and 5.4b). In Wedza, combined application of compound Z and ZnO resulted in significantly higher Zn uptake, recording a 2.5 fold increase over the non-Zn treatment. In Makoni, sole application of compound Z superceded the control by up to 200%. Higher nutrient uptake ranges in Wedza than in Makoni suggest nutrient levels increase over time with farmer management of fields.

Maize grain Zn uptake measured during the 2009/10 growing season ranged from 54.0 – 118.8 and 50.5 – 101.0 g ha<sup>-1</sup> in Wedza and Makoni respectively (Figures 5.5a and 5.5b) with grain obtained from application of NPK fertilizer only giving the lowest Zn uptake in both areas. During this season, highest Zn uptake concentrations were from the treatment involving combined application of basal ZnO + foliar ZnSO<sub>4</sub>.7H<sub>2</sub>O. Sole application of either basal ZnO

or foliar Zn fertilizers measured significantly higher grain Zn uptake from the non Zn treatment.

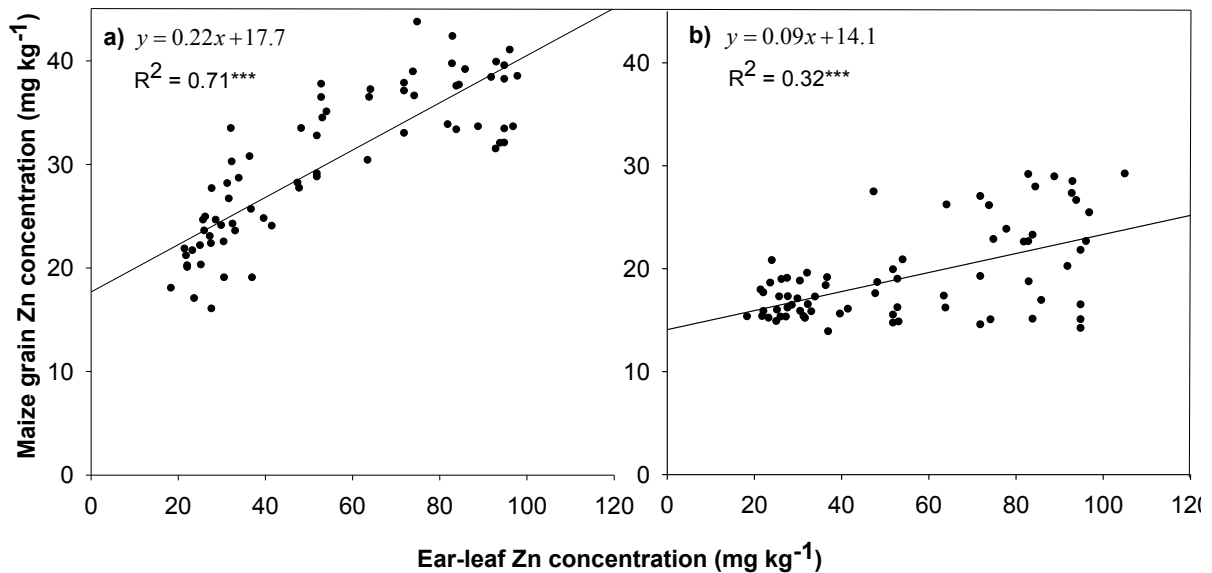


**Figure 5.4** Maize grain Zn uptake measured after application of different Zn fertilizers during the 2008/09 season in a) Wedza and b) Makoni. SED-Standard error of the difference of means.



**Figure 5.5** Maize grain Zn uptake measured during the 2009 – 10 growing season after basal and foliar zinc application in eastern Zimbabwe. \* = residual fertility was assumed.

In both study areas, there was a significant linear relationship between maize ear leaf and grain Zn concentration ( $R^2 > 0.70$ ), with maize grain Zn concentration increasing with an increase in ear leaf Zn concentration (Figure 5.6).



**Figure 5.6** Relationship between ear-leaf and grain Zn concentrations in a) Wedza and b) Makoni. \*\*\* means significant relationship at  $P < 0.05$

#### **5.5.8 Effect of different Zn- based fertilizer formulations on grain N, P and Ca concentration**

In Wedza, significant differences ( $P < 0.05$ ) in N and P concentrations in maize grain were observed during the 2008/09 cropping season (Table 5.7). No such significant differences in Ca were measured. Grain N and P concentrations ranged between 1.46 – 1.84% and 0.24 – 0.33%, respectively, (Table 5.7). Differences observed in Wedza might have been due to N and P contained in foliar Zn fertilizers which were not applied in Makoni. Application of foliar OMEX 2 fertilizer resulted in significantly higher N and P concentrations of 20% N and 38% P possibly because the fertilizer had a high N content of 12%. Apart from this, very low yields measured in this treatment (OMEX 2) might have led to less dilution in these grains. Though

Ca concentrations were within a wide range of 94 – 212 mg kg<sup>-1</sup>, no significant differences were measured among treatments (P>0.05).

In Makoni, lower N and P values of 1.40% and 0.25%, respectively were measured during the 2008/09 cropping season (Table 5.7). Similar to study sites, no significant differences in grain N, P and Ca concentrations were measured during the 2009/10 cropping season (data not shown). Lower values of P and Ca which ranged from 0.18–0.34% and 44.6–85.0 mg kg<sup>-1</sup>, respectively may be attributed to repeated application of Zn- based fertilizer formulations which could have resulted in poor uptake of these nutrients.

#### ***5.5.9 Influence of different fertilizers on phytic acid and calcium and their interaction with zinc***

Significant differences in PA: Zn molar ratios were observed among treatments (P<0.05) in Wedza (Table 5.8). However, such significant differences were only observed during the second cropping season in Makoni (Table 5.9). In Wedza, the PA: Zn molar ratios measured during the 2008/09 cropping season were within the range of 57.3 – 109.0 (Table 5.8). During the 2009/10 season, PA: Zn ratios ranged from 52.9 – 116.4 with the non-Zn fertilizer treatment consistently having the highest ratios (Table 5.9) possibly due to lack of external Zn application.

Common to seasons, co-application of basal Zn and foliar ZnSO<sub>4</sub>.7H<sub>2</sub>O greatly reduced the PA: Zn molar ratio by up to 90% and 120%, respectively against the non-Zn treatment. In sole applications, both basal and foliar Zn fertilizers resulted in significantly higher ratios across seasons compared to their combinations.



**Table 5.7** Effect of basal and foliar Zn fertilizers on grain N, P and Ca concentrations of maize grown in Wedza and Makoni smallholder farming areas

Treatment	Wedza			Makoni		
	N	P	Ca	N	P	Ca
	%	%	mg kg <sup>-1</sup>	%	%	mg kg <sup>-1</sup>
PKS + AN (control)	1.53	0.27	100	1.22	0.23	107
PKS + *ZnO+ AN	1.63	0.28	112	1.22	0.22	74.9
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.60	0.27	131	1.10	0.23	93.4
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.61	0.27	134	1.16	0.22	81.7
PKS + §OMEX Type 1+ AN	1.64	0.31	118	1.27	0.23	79.1
PKS + §OMEX Type 2+ AN	1.84	0.33	94	1.20	0.24	71.9
*Compound Z + AN	1.46	0.25	105	1.21	0.23	68.0
PKS + *MESZ + AN	1.59	0.28	111	1.40	0.25	86.0
PKS + *Compound Z+ AN	1.51	0.25	131	1.19	0.21	66.4
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.55	0.25	110	1.12	0.22	65.1
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1.55	0.26	212	1.23	0.25	82.1
PKS + *Compound Z + *ZnO+ AN	1.49	0.24	178	1.18	0.22	95.9
SED	0.06 <sup>**</sup>	0.01 <sup>**</sup>	47.0 <sup>ns</sup>	0.10 <sup>ns</sup>	0.02 <sup>ns</sup>	17.5 <sup>ns</sup>
Mean	1.58	0.27	128	1.21	0.23	80.9
C.V (%)	6.5	6.5	64.2	10.3	11.3	25.6

\* means Zn fertilizer was basal applied. § means Zn fertilizer was foliar applied. \*\* means significant treatment differences at P<0.05. ns- treatment means not significantly different at P<0.05.

These figures were however, significantly lower than those attained in the non – Zn treatment. Apart from the non-Zn treatment that measured a PA: Zn molar ratio of 7% higher in the 2<sup>nd</sup> growing season, lower PA: Zn molar ratios were measured in Wedza during the 2009/10 season than in the 1<sup>st</sup> season (Table 5.9).

In Makoni, the PA: Zn molar ratios ranged from 70.4 – 99.2 during the 2008/09 season (Table 5.8). During the 2009/10 cropping season, residual basal Zn fertility and foliar Zn fertilizers resulted in the lowest PA: Zn molar ratio, but even these still exceeded the critical value of <15. Sole application of foliar Zn fertilizers resulted in a significant reduction in PA: Zn molar ratios than residual basal Zn fertility. Apart from this, PA: Zn ratios in the 2<sup>nd</sup> season were lower than those measured in the 2008/09 cropping season and ranged between 48.2 and 69.0 (Table 5.9). The results however indicated a general decrease in the PA: Zn molar ratios following repeated application of Zn fertilizer.

The Ca x PA: Zn molar ratio, which is the most appropriate ratio for estimating bioavailability of Zn was within extremely wide ranges of 6 175 – 12 683 and 5 916 – 9 887 in Wedza and Makoni respectively, during the 2008/09 season (Table 5.8). Significant ( $P < 0.05$ ) differences in Ca x PA: Zn molar ratios were observed among treatments during the 2009/10 cropping season. In the 2<sup>nd</sup> season, ratios were lower and ranged from 2 735 – 5 529 in Wedza and 2 396 – 4 144 in Makoni (Table 5.9) possibly due to an increase in grain Zn concentration. Across seasons and study sites, the Ca x PA: Zn molar ratios exceeded the critical value of  $\leq 200$ , with the non- Zn treatment consistently yielding the highest values. This implies poor mineral bioavailability in maize produced without Zn fertilizers.

**Table 5.8** Effect of Zn fertilization on PA, PA: Zn and Ca x PA: Zn molar ratios in Wedza and Makoni smallholder farming areas in Zimbabwe

Treatment	Wedza			Makoni		
	PA (mg kg <sup>-1</sup> )	PA: Zn	Ca x PA: Zn	PA (mg kg <sup>-1</sup> )	PA: Zn	Ca x PA: Zn
PKS + AN (control)	1 776 <sup>b</sup>	109 <sup>f</sup>	12 683	1 463	99.2	9 887
PKS + *ZnO+ AN	1 808 <sup>b</sup>	80.7 <sup>c</sup>	9 063	1 436	70.4	5 222
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1 738 <sup>b</sup>	65.2 <sup>b</sup>	8 048	1 494	96.8	8 931
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1 753 <sup>b</sup>	58.7 <sup>ab</sup>	7 430	1 400	70.7	5 619
PKS + §OMEX Type 1+ AN	2 047 <sup>c</sup>	85.9 <sup>cd</sup>	10 035	1 483	93.6	7 423
PKS + §OMEX Type 2+ AN	2 127 <sup>c</sup>	86.1 <sup>cd</sup>	7 850	1 537	97.7	7 008
*Compound Z + AN	1 605 <sup>ab</sup>	87.1 <sup>cd</sup>	9 205	1 473	97.6	6 697
PKS + *MESZ + AN	1 830 <sup>b</sup>	100.8 <sup>ef</sup>	10 853	1 645	97.5	8 395
PKS + *Compound Z+ AN	1 633 <sup>ab</sup>	89.5 <sup>d</sup>	11 482	1 336	93.2	6 195
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1 653 <sup>ab</sup>	57.3 <sup>a</sup>	6 175	1 406	93.2	6 381
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1 699 <sup>ab</sup>	67.7 <sup>b</sup>	10 779	1 621	98.7	8 095
PKS + *Compound Z + *ZnO+ AN	1 580 <sup>a</sup>	68.2 <sup>b</sup>	10 762	1 415	76.7	7 282
SED	67 <sup>**</sup>	3.9 <sup>**</sup>	2 824 <sup>ns</sup>	141 <sup>ns</sup>	8.6 <sup>ns</sup>	1 519 <sup>ns</sup>

\* means Zn source was basal applied. § means Zn source was foliar applied. PA denotes phytic acid. \*\* denotes significant differences among treatments at p<0.05. ns – not significantly different (P>0.05).

**Table 5.9** Assessment of residual Zn effects and foliar Zn fertilizer application on PA, PA: Zn and Ca x PA: Zn molar ratios in Wedza and Makoni maize production systems, Zimbabwe

Treatment	Wedza			Makoni		
	PA mg kg <sup>-1</sup>	PA: Zn	Ca x PA: Zn	PA mg kg <sup>-1</sup>	PA: Zn	Ca x PA: Zn
PKS + AN (control)	2 112	116.4 <sup>d</sup>	5 529 <sup>b</sup>	1 290	69.0 <sup>c</sup>	4 144 <sup>b</sup>
PKS + *ZnO+ AN	2 082	74.2 <sup>b</sup>	4 734 <sup>b</sup>	1 201	48.2 <sup>a</sup>	2 619 <sup>ab</sup>
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	1 982	56.8 <sup>ab</sup>	3 418 <sup>ab</sup>	1 352	48.8 <sup>a</sup>	2 396 <sup>a</sup>
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	2 035	52.9 <sup>a</sup>	2 735 <sup>a</sup>	1 426	46.6 <sup>a</sup>	3 961 <sup>b</sup>
PKS + §OMEX Type 1+ AN	2 192	68.5 <sup>b</sup>	3 625 <sup>ab</sup>	1 225	60.3 <sup>b</sup>	2 691 <sup>ab</sup>
PKS + §OMEX Type 2+ AN	2 180	61.4 <sup>ab</sup>	3 454 <sup>ab</sup>	1 271	52.7 <sup>ab</sup>	2 942 <sup>ab</sup>
*Compound Z + AN	2 108	89.9 <sup>c</sup>	4 969 <sup>b</sup>	1 207	58.9 <sup>b</sup>	4 097 <sup>b</sup>
PKS + *MESZ + AN	2 247	91.0 <sup>c</sup>	4 684 <sup>b</sup>	1 400	69.0 <sup>c</sup>	3 235 <sup>ab</sup>
PKS + *Compound Z+ AN	2 106	89.4 <sup>c</sup>	5 398 <sup>b</sup>	1 301	60.5 <sup>b</sup>	3 528 <sup>b</sup>
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	2 029	60.2 <sup>ab</sup>	3 824 <sup>ab</sup>	1 284	51.6 <sup>a</sup>	2 717 <sup>ab</sup>
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	2 100	66.9 <sup>b</sup>	3 118 <sup>ab</sup>	1 555	61.0 <sup>b</sup>	3 201 <sup>ab</sup>
PKS + *Compound Z + *ZnO+ AN	2 101	75.3 <sup>b</sup>	4 069 <sup>ab</sup>	1 473	60.4 <sup>b</sup>	3 042 <sup>ab</sup>
SED	72 <sup>ns</sup>	6.2 <sup>***</sup>	924 <sup>***</sup>	119 <sup>ns</sup>	3.5 <sup>***</sup>	539 <sup>**</sup>

\* means residual Zn fertility. § means fertilizer was foliar applied. PA means phytic acid. \*\* denotes significant differences among treatments at p<0.05. \*\*\* denotes significant differences among treatments at p<0.01. ns means not significantly different (P>0.05).

#### ***5.5.10 Assessment of Zn fertilization and residual fertility on plant available soil Zn***

Application of different Zn- based fertilizer formulations significantly ( $P < 0.05$ ) increased plant available soil Zn (Table 5.10) with no influence on all other measured soil chemical parameters (data not shown). Plant available soil Zn ranged from 1.20-4.37 mg kg<sup>-1</sup> in Wedza and 0.54-2.33 mg kg<sup>-1</sup> in Makoni during the 2008/09 cropping season (Table 5.10). When residual fertility was tested during the 2<sup>nd</sup> cropping season, plant available soil Zn ranged between 1.03 and 4.51 mg kg<sup>-1</sup> in Wedza and 0.49 and 3.17 mg kg<sup>-1</sup> in Makoni (Table 5.10).

Consistently, soils collected from combinations of basal and foliar Zn fertilizer treatments had the highest concentration, which was about 3-fold higher than the non-Zn treatment. On the other hand, residual fertility exhibited relatively higher plant available soil Zn concentrations than those measured during season of application. For example, the sole basal ZnO treatment in Wedza had 2.92 mg kg<sup>-1</sup> plant available Zn during the 1<sup>st</sup> cropping season and 3.87 mg kg<sup>-1</sup> during the 2<sup>nd</sup> cropping season, amounting to a 33% increase. This shows that mineralization and availability of the fertilizer increased with an increase in time.

Sole application of either basal or foliar Zn fertilizer significantly increased plant available soil Zn by a maximum of 285% over the control treatment (Table 5.10). At the end of the 2009/10 cropping season, the non-Zn treatment measured the lowest Zn concentration of 1.20 mg kg<sup>-1</sup> in Wedza and 0.49 mg kg<sup>-1</sup> in Makoni. These values were lower than the initial concentration by 13% and 18%, respectively.

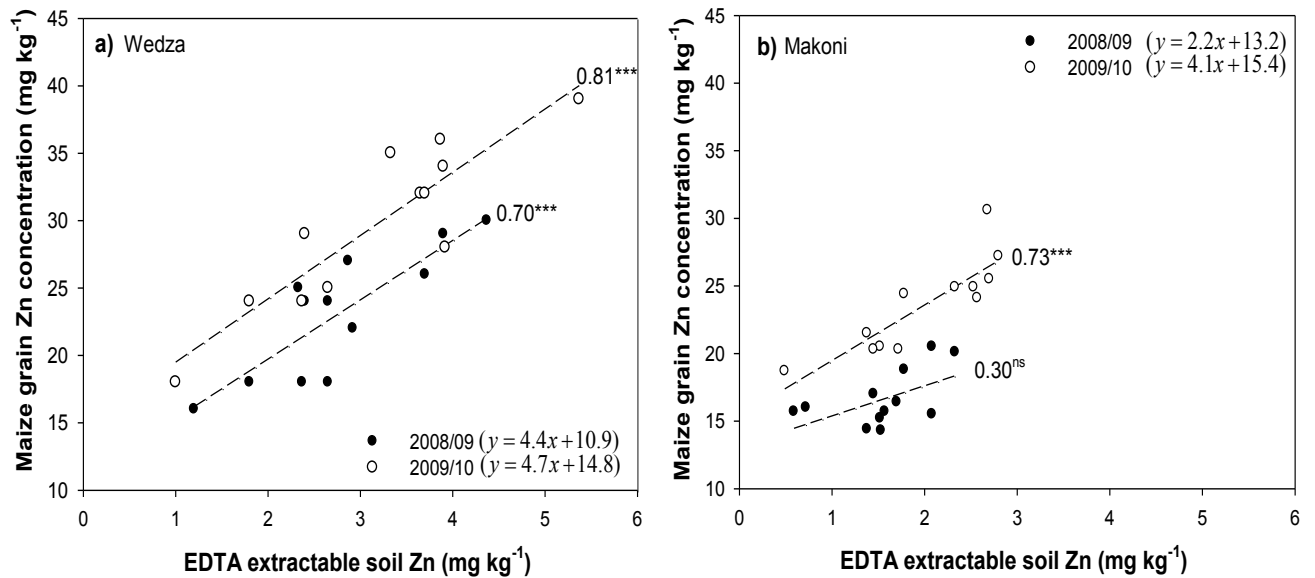
**Table 5.10** Effect of different Zn fertilizer formulations and residual fertility on plant available Zn in Wedza and Makoni smallholder farms in Zimbabwe

Treatment	Plant available soil Zn concentration (mg kg <sup>-1</sup> )			
	2008/09		2009/10	
	Wedza	Makoni	Wedza	Makoni
<b>Initial nutrient concentration</b>	<b>1.35</b>	<b>0.60</b>	<b>1.35</b>	<b>0.60</b>
PKS + AN (control)	1.20 <sup>a</sup>	0.54 <sup>a</sup>	1.03 <sup>a</sup>	0.49 <sup>a</sup>
PKS + *ZnO+ AN	2.92 <sup>bc</sup>	2.08 <sup>bc</sup>	3.87 <sup>bc</sup>	2.33 <sup>bc</sup>
PKS + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	2.87 <sup>bc</sup>	2.08 <sup>bc</sup>	3.12 <sup>b</sup>	2.80 <sup>c</sup>
PKS + *ZnO + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	4.37 <sup>c</sup>	2.33 <sup>c</sup>	4.51 <sup>c</sup>	3.17 <sup>c</sup>
PKS + §OMEX Type 1+ AN	2.65 <sup>bc</sup>	0.72 <sup>a</sup>	3.42 <sup>bc</sup>	1.72 <sup>b</sup>
PKS + §OMEX Type 2+ AN	2.33 <sup>ab</sup>	1.57 <sup>bc</sup>	3.21 <sup>bc</sup>	2.53 <sup>bc</sup>
*Compound Z + AN	2.37 <sup>ab</sup>	1.52 <sup>b</sup>	3.45 <sup>bc</sup>	1.98 <sup>bc</sup>
PKS + *MESZ + AN	2.65 <sup>bc</sup>	1.45 <sup>b</sup>	3.70 <sup>bc</sup>	1.95 <sup>bc</sup>
PKS + *Compound Z+ AN	1.80 <sup>ab</sup>	1.38 <sup>b</sup>	3.25 <sup>bc</sup>	2.01 <sup>bc</sup>
PKS + *Compound Z + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	3.90 <sup>c</sup>	1.53 <sup>bc</sup>	4.17 <sup>c</sup>	2.93 <sup>c</sup>
PKS + *MESZ + §ZnSO <sub>4</sub> .7H <sub>2</sub> O+ AN	3.70 <sup>c</sup>	1.70 <sup>bc</sup>	3.92 <sup>c</sup>	2.99 <sup>c</sup>
PKS + *Compound Z + *ZnO+ AN	2.40 <sup>b</sup>	1.78 <sup>b</sup>	3.95 <sup>c</sup>	3.09 <sup>c</sup>
Mean	2.76	1.56	3.47	2.33
SED	0.59	0.40	0.39	0.48
Significance	***	**	**	**

\* means Zn source was basal applied. § means Zn source was foliar applied. <sup>1</sup> means residual basal fertility. \*\* = treatment effect significant at P < 0.05; \*\*\* = treatment effect significant at P < 0.01. Homogeneous groups are denoted by the same letter.

### *5.5.11 Relationship between plant available soil Zn and grain Zn as affected by application of different Zn- based fertilizer formulations*

In Wedza, a significant (P<0.05) positive linear relationship was observed between soil Zn and maize grain Zn concentration (R<sup>2</sup>>0.80) (Figure 5.7) with combined application of ZnO and ZnSO<sub>4</sub>.7H<sub>2</sub>O consistently resulting in the highest EDTA-extractable soil and maize grain Zn concentrations. In Makoni, a significant linear relationship was observed during the 2009/10 cropping season (R<sup>2</sup>=0.73). Regression analysis showed that grain Zn concentrations of ≥25 mg kg<sup>-1</sup> can only be attained at available soil Zn concentrations of >2.0 mg kg<sup>-1</sup> (Figure 5.7).



**Figure 5.7** Relationship between maize grain and soil Zn concentrations after zinc fertilization in a) Wedza and b) Makoni, Zimbabwe.

## 5.6 Discussions

### 5.6.1 Influence of Zn- based fertilizer formulations on maize grain yields

Fertilization with Zn in addition to NPK significantly increased maize grain yields by 62%. The results highlight the importance of micronutrient fertilization in maize- based cropping systems on sandy soils where yields of up to 3 t ha<sup>-1</sup> are rarely attained. Improved maize grain yields derived from application of basal micronutrients including Zn in combination with macro-nutrients have been well quantified under similar climatic conditions in Zimbabwe (Tagwira, 1991; Zingore, 2006; Masvaya, 2007) and in Asia (Tandon, 1995).

The results further suggest that there is a need for starter N to achieve early vigorous growth of plants grown on inherently N deficient soils. Zinc is required mainly during the early stages of growth for enhanced root development which promotes uptake of essential nutrients for growth (Alloway, 2008). It is during these early stages of growth when Zn deficiency symptoms are noticed. Benefits of Zn on grain yield were significantly manifested in combinations of basal and foliar Zn fertilizers and such results have been

reported by several authors (Yilmaz et al., 1997; Potarzycki and Grzebisz, 2009). In a study conducted by Rengel and Graham (1995) an increase in seed Zn significantly improved root and shoot growth of wheat plants under Zn deficiency. Zinc does not only promote root growth but also alleviate biotic and abiotic stress events in crops grown on farmers' fields (Cakmak, 2000). Adequate Zn fertilization can mitigate plant damages by high sunlight intensities. This is important especially in view of global climate changes.

Benefits of sole basal and foliar fertilization were not expressed in increased grain yield suggesting yield advantages could only be realized when the two fertilizer formulations are applied together. The non-Zn treatment produced the least yields across seasons. A decrease in attainable yields of maize of 10-22% has been reported due to inherent deficiency of required nutrients in the soil and inadequate application of fertilizers (Subedi and Ma, 2009). Zinc is important for increasing crop yields, especially in sensitive crops such as maize.

#### ***5.6.2 Ear-leaf nutrient concentrations under different Zn fertilizer formulations***

Zinc fertilization resulted in significantly higher maize ear-leaf Zn concentrations than the non-Zn treatment. Walsh and Beaton (1973), interpreted maize ear leaf concentrations, in mg Zn kg<sup>-1</sup>, at silking as follows: 11 – deficient, 15 – low, 15 – 70 (sufficient), >71 – high. The results showed that all ear-leaf concentrations measured during the two growing seasons were above the deficiency limit of 15 mg Zn kg<sup>-1</sup>. This might mean that maize has the potential of growing in Zn deficient soils during the early stages of development and not show any symptoms of deficiency, a condition known as hidden deficiency (Alloway, 2004). When it comes to fruit development, there is need for external fertilization because during this stage of growth, the plant requires sufficient amount of nutrients. Overall,



maize ear leaf Zn concentration was significantly improved by combined application of basal and foliar Zn fertilizers. This is largely attributed to an increase in available Zn in the soil. When residual fertility was tested, ear- leaf samples collected from sole foliar Zn treatments had significantly higher Zn concentrations compared to basal residual Zn treatments. Results suggest that for a significant increase in plant Zn concentration which will contribute to grain Zn uptake, there is need to apply Zn as foliar in addition to basal fertilizers. An improved micronutrient mass fraction in the soil is essential for increased plant Zn concentrations.

### ***5.6.3 Influence of different fertilizer formulations on maize grain Zn concentrations and uptake***

Combined application of basal and foliar Zn fertilizers resulted in the highest grain Zn concentrations, suggesting that the two groups of formulations are complementary. Basal Zn fertilizers were likely available for plant uptake during early stages of growth, while foliar Zn was taken up at fruit development when the crop had high demand for the nutrient. Results are in accordance with findings from Central Anatolia, Turkey where the most effective method for increasing Zn in grain was the soil + foliar application method that resulted in about 3.5 fold increase in grain Zn concentration (Yilmaz et al., 1997).

Generally, application of Zn in combination with NPK fertilizers increased Zn uptake from the soil to the grain, resulting in an increase in maize grain nutritional quality. Malakouti (2008) concluded that application of Zn with mixed fertilizers particularly N-based fertilizers could enhance Zn uptake. On the other hand, sole application of foliar fertilizers resulted in significantly higher grain Zn concentration than basal Zn containing fertilizers.

Foliar  $\text{ZnSO}_4$  gave the highest grain Zn concentrations indicating high solubility of  $\text{ZnSO}_4$  and increased nutrient uptake as  $\text{Zn}^{2+}$  (Alloway, 2004) compared to other formulations.

Application of foliar sprays increases the speed with which nutrients are taken up and has been found to be a quick and effective way of correcting nutrient deficiencies in wheat (Erenoglu et al., 2002) and maize (Grzebisz et al., 2008). Foliar fertilizers were applied twice at tasselling and silking to increase nutrient uptake and benefit fruit development. After foliar spraying, plant's activity such as photosynthesis and chlorophyll production are known to increase (Kuepper, 2003). Increase in photosynthesis rate consequently increases water requirements thus uptake of water and nutrients from roots through the plant's vascular system is increased. Recent results showed promise for foliar application of Zn fertilizers to improve grain Zn concentrations in cereals (Cakmak et al., 2010b). Due to labour constraints and lack of equipment, practicalities of using knap sack sprayers for large pieces of land remains questionable. However, for smallholder farmers who grow maize on small pieces of land or practice horticulture in gardens, knowledge on dilution of foliar Zn fertilizers should be disseminated.

The composition of Zn in basal fertilizers also influenced grain Zn concentration. In basal form, application of ZnO resulted in a maximum increase in grain Zn of 37.5% against the non Zn treatment compared to other formulations. This may be due to the concentration of Zn in ZnO of as much as 78%, which was higher than the other fertilizers. Apart from solubility of a fertilizer, composition of Zn in the fertilizer is also important for the realization of high grain Zn concentrations.

#### ***5.6.4 Indicators of Zn bioavailability as affected by different Zn- based fertilizer formulations***

Significant differences in PA: Zn and Ca x PA: Zn molar ratios were observed, with co-application of basal and foliar Zn fertilizers measuring the lowest ratios in the 2<sup>nd</sup> cropping season. The results indicate that repeated Zn fertilization could be the only assurance for increasing the level of nutrient bioavailability in grains by reducing the impacts of P and Ca on Zn. Similar findings were recorded by Erdal et al., (2002).

Apart from Zn fertilization, pre- and post-harvest phytate reduction practices that include fermentation, dehusking and washing of grain samples are required to enhance Zn bioavailability in humans. Reductions in phytic acid concentrations in cereals after fermentation have been reported in wheat and sorghum by Khan et al., (1986) and pearl millet (Kheterpaul and Chauhan, 1991).

High PA: Zn molar ratios and consistent increase over seasons in the non-Zn treatment may be attributed to repeated application of P fertilizers and lack of external Zn fertilization which results in extremely high phytate in the grain. Malakouti (2008) also observed that wheat grown on calcareous soils under imbalanced fertilization resulted in PA: Zn molar ratios exceeding 40. Zinc deficiency has been reported to enhance P transporter genes in root cells and enhance P accumulation in plants (Huang et al., 2000). To reduce effect of P fertilization on potentially Zn deficient soils, continuous use of macro- and micro-nutrient fertilizers with NPK and Zn is important in producing staple cereal grains of high nutritional value.

### ***5.6.5 Relative contribution of Zn fertilizers to build up of available soil Zn***

Application of different Zn- based fertilizer formulations resulted in significantly higher EDTA extractable soil Zn than the non- Zn treatment. Although some authors say Zn does not stay soluble in the soil for long due to soil chemical properties which render the nutrient unavailable (Tagwira, 1991; Alloway, 2004; Zingore 2006), present investigations showed that, irrespective of method of application, available soil Zn measured in both sites was significantly higher than the initial values. This may be attributed to favourable low pH values of between 4.4 and 4.5 that probably enhanced Zn availability. Some studies have also shown that under low pH , Zn is soluble and available for plant uptake (Basta et al., 2005).

Zinc availability could also have been enhanced by exclusive fertilization which improved Zn bioavailability. Results suggest that there is a significant increase in micronutrient mass fractions when basal and foliar Zn fertilizers are applied in combinations. Use of sole foliar and basal Zn fertilizers proved a possible avenue for improving plant available soil Zn as indicated by EDTA-extractable Zn concentrations above the deficiency limit of  $<1.5 \text{ mg kg}^{-1}$ . Residual Zn effects measured available Zn concentrations significantly above the non-Zn treatment suggesting that residual fertility of Zn can persist for over one season. This becomes an economical way of replenishing inherently low Zn stocks in smallholder maize- based cropping systems as farmers do not have to re-apply basal Zn fertilizers every season. Several authors have recommended application of basal Zn fertilizers once in every 3-4 years (Tanner, 1975; Tagwira, 1991; Martens and Westermann, 1991).

Continuous cropping with no external Zn fertilization resulted in depletion of available Zn as indicated by reduced concentrations of EDTA-extractable Zn over the two cropping

seasons. On smallholder farms, inappropriate soil fertility management by continuous cropping with inadequate supply of nutrients is considered a major threat, not only to food production caused by nutrient mining (Bekunda and Manzi, 2003) but also to ecosystem viability (Pinstup-Andersen, 1999; Tillman, 1999). A significant positive linear relationship between available soil Zn and maize grain Zn concentration was observed implying that Zn fertilization could contribute to improved soil fertility, crop nutrition and consequently human nutrition and health.

## **5.7 Conclusions**

The study showed that application of Zn containing fertilizers significantly improved yields and Zn concentration of maize grain compared to the non-Zn treatment. Combined use of basal Zn fertilizers such as ZnO with foliar Zn fertilizers measured the highest grain Zn concentrations, however not significantly different from sole application of foliar ZnSO<sub>4</sub> and OMEX 2. Given that most smallholder farmers are resource constrained and might fail to use combinations of both methods, foliar application of Zn is effective for improved grain Zn. Although soil applications were not as efficient as foliar applications in the first season, residual basal Zn fertility resulted in grain Zn concentrations not significantly different from seasonal foliar application. This implies that if available sources of Zn are used, there is potential for improved grain Zn and observed residual benefits therefore suggest frequent Zn fertilization becomes unwarranted. There is need for fertilizer manufacturing companies to produce micronutrient-containing compound fertilizers which are economical to farmers, putting into consideration the composition of Zn in such fertilizers.

## Chapter 6

### **Interactions of zinc with organic and inorganic fertilizers: Implication on improving crop productivity and grain nutrient concentration<sup>§</sup>**

#### **6.1 Abstract**

Soil fertility management research efforts to increase productivity of staple cereal crops in sub-Saharan Africa have paid little attention to soil micronutrients deficiencies. Combined use of organic and inorganic macronutrient fertilizers is the main soil fertility management option explored. Little attention has been paid on additional value of micronutrients especially Zn under such fertility combinations. An on-farm researcher managed experiment was carried out in Wedza District during the 2009/10 and 2010/11 season to assess the added benefits of Zn fertilizer on maize yield and grain quality when co-applied with farmers' locally available organic nutrient resources and nitrogen (N), phosphorus (P), potassium (K) fertilizers. Results showed that Zn gave added yield benefits to both sole mineral and mineral and organic fertilizer combinations. Combinations of organic and inorganic NPK and Zn fertilizers resulted in superior grain yields. In the first cropping season (2009/10), co-application of leaf litter at 5 t ha<sup>-1</sup> with mineral fertilizers produced 3.9 t ha<sup>-1</sup>; translating to 1.3 times more yields than attained under sole mineral fertilizers (90 kg N ha<sup>-1</sup> and 26 kg P ha<sup>-1</sup>). In the subsequent season, residual organic fertility gave 2 t ha<sup>-1</sup> more grain yields than sole mineral fertilizers. Zinc application resulted in a significant increase in grain Zn concentration in both sole mineral fertilizers and combinations. Consistently, maize grain under combination of mineral NPK and Zn and leaf litter gave the highest grain Zn concentration of up to 33 mg kg<sup>-1</sup>. An increase of 67% in grain Zn concentration against a 29% increase in yield in the sole mineral fertilizer treatment showed there was much more benefit in grain quality than yield after external Zn application. Apparently, treatments without Zn fertilizer produced the highest grain P concentration of up to 0.33% compared with Zn fertilized treatments (< 0.25% P). Phosphorus and Zn fertilization resulted in appreciable build up of soil available P and ethylenediaminetetraacetic acid (EDTA)-extractable Zn of 6.5 mg kg<sup>-1</sup> and 5.4 mg kg<sup>-1</sup>, respectively from 5.2 mg P kg<sup>-1</sup> and 1.15 mg Zn kg<sup>-1</sup>. It was concluded that integrated soil fertility management packages as currently presented to smallholder farmers is limited by lack of micronutrients whose demand is greater in sole mineral fertilizers than in combinations of organic and inorganic fertilizers. Currently the effect of Zn-P interactions on staple maize grain nutrition remains a knowledge gap.

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## 6.2 Introduction

Nitrogen, P and Zn deficiencies among other nutrients, have been known to limit crop growth in sandy soils in smallholder cropping systems (Grant, 1981; Vanlauwe et al., 2001; Giller and Mapfumo, 2002). Nitrogen and P are essential for good vegetative growth and grain development in maize production. The quantity required of these nutrients, particularly N depends on residual fertility, organic matter content, tillage method and light intensity (Kang, 1981). Nitrogen makes up 1 – 4% of dry matter of plants (Anonymous, 2000; Palm et al., 2001) and when N levels are sub-optimal, growth is reduced. Phosphorus is an integral component of the complex nucleic acid structure in plants which regulate protein synthesis (Alloway, 2004). Micronutrients particularly Zn, is also important in maize production and has positive contributions to growth such as improvements in seedling vigour, pathogen resistance, competition against weeds and enhanced yields (Graham and Rengel, 1993; Rengel and Graham, 1995). Increasing concentrations of Zn in cereal grains is high priority in alleviation of micronutrients deficiency in human population (Cakmak, 2002). Application of inorganic N, P and Zn to deficient soils probably will provide a solution to correction of nutrient deficiency (Olsen and Barber, 1977; Rehm et. al., 1980).

Organic matter, cattle manure, poultry manure, leaf litter, ash and compost in particular are usually added to soils to improve their properties and fertility levels. Cattle manure is an important component of soil fertility management in many regions of sub-Saharan Africa (Giller et al., 1998). Although crop response to cattle manure application on farmers' fields is highly variable due to a number of factors which may include handling, chemical composition, frequency and rates of application, known benefits are often quite substantial. Beneficial

effects of manure include soil moisture retention, improved soil structure, improved soil fertility through increased nutrient availability (P, Ca, Mg and Zn) and enhanced nutrient use efficiency (Grant, 1967; Stevenson, 1994; Rengel, 1999; Khoshgoftarmanesh et al., 2009).

On farmers' fields, application of organic amendments has been focusing mainly on improving crop yields and retaining soil moisture. The effective utilization of P and Zn present in cattle and poultry manure is evidence of the importance of organic matter in increasing the availability of these elements in soils (Thomas and Mathers, 1979; Prasad et al., 1984). Azevedo and Stout (1974) reported that the P in poultry manure was equally available as inorganic sources but other investigators (Olsen and Barber, 1977) argue that the value of manure P is greater than that of the same amounts of inorganic P. The effect in all cases was attributed to the complexing agents in manure which is responsible for supplying chelating agents that aid in retention of soluble nutrients which are more available to plants. Chelation of Zn and other micronutrients (Fe, Cu, Mn) by organic matter holds these nutrients in forms more accessible by roots within the rhizosphere and retards formation of insoluble solid forms such as oxides and carbonates in the soil (Schulin et al., 2009). Gao et al., (2000) found that manure was a better source of Fe, Mn and Zn compared to synthetic fertilizers, though it accelerated depletion of Cu.

Manure does not only supply large amounts of Zn to soil relative to mineral fertilizers, but also promotes biological and chemical reactions that result in the dissolution of non-available Zn (Wei et al., 2006). Woodland litter also plays a significant role in nutrient replenishment and moisture retention. Upon decomposition, natural chelates which maintain Zn as a soluble ion available for plant uptake are released (Muller-Samann and Kotshi, 1994).



Soil fertility management research and development efforts to increase crop productivity of food security crops have paid little attention to soil micronutrient deficiencies. Studies conducted by Manzeke et al., (2012) showed that use of locally available organic resources by smallholder farmers is insufficient to improve grain Zn quality. Due to increasing evidence of widespread micronutrient deficiencies, particularly Zn in maize- based cropping systems on smallholder farms, there is need to assess the added benefits of Zn fertilizer on maize yield and grain quality when co-applied with farmers' locally available organic nutrient resources and NPK fertilizers commonly available on markets. With regard to this, the present study was designed to:

1. Assess the effect of N, P and Zn application in combination with cattle manure or leaf litter on maize productivity, grain Zn concentration and uptake.
2. Determine the potential role of organic fertilizers, cattle manure and leaf litter as sources of Zn and P in maize production.

### **6.3 Materials and methods**

#### ***6.3.1 Site selection***

Initial random characterization of different farmers' fields for available soil Zn was conducted in Wedza district during the 2009 – 2010 cropping season. The soil samples (0 – 20 cm depth) were collected from 10 random points per field using an auger. A researcher-managed experiment was established on a farmer's field where the soil was a loamy sand with EDTA-extractable soil Zn of  $<1.5 \text{ mg kg}^{-1}$ .

### 6.3.2 Experimental treatments

Land was prepared by conventional ploughing, and 13 treatments were laid out in plots measuring 4.5 m x 5 m. The design was a randomized complete block design (RCBD) with three replicates. Blocking was based on soil fertility within the field. Basal broadcasting of PKS (32% P<sub>2</sub>O<sub>5</sub>: 16% K<sub>2</sub>O: 5% S) was done at high and low applications of 26 kg P ha<sup>-1</sup> and 14 kg P ha<sup>-1</sup> respectively. Broadcast application of basal ZnSO<sub>4</sub>.7H<sub>2</sub>O was done before planting at 11 kg Zn ha<sup>-1</sup>. Control treatments (90 kg N ha<sup>-1</sup> + 26 kg P ha<sup>-1</sup>) and (30 kg N ha<sup>-1</sup> + 14 kg P ha<sup>-1</sup>) were included where no Zn containing fertilizer was applied (Table 6.1). An absolute control treatment, without any fertilizer was also included. Leaf litter and cattle manure were broadcast solely or in combination with NPK and Zn containing inorganic fertilizers to selected treatments at 5 t ha<sup>-1</sup> (Table 6.1).

**Table 6.1** Treatment structure to investigate the influence of N, P and Zn application, in combination with organic nutrient resources, on maize productivity and nutrient uptake

Treatment	Nutrients added
1	90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> ( <b>Control 1</b> )
2	90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn
3	30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> ( <b>Control 2</b> )
4	30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn
5	90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn
6	90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>
7	30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn
8	30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>
9	Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>
10	Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn
11	Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>
12	Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn
13	Absolute control ( <b>Control 3</b> )

### ***6.3.3 Determination of nutrient composition of organic nutrient resources***

Cattle manure and leaf litter samples were collected from the selected farmer's homestead and air dried to determine their nutrient composition. After air drying, cattle manure was prepared by passing through a 2 mm sieve. Particles >2 mm were discarded. Leaf litter was ground in a stainless steel mill. Both samples were taken to the laboratory for analyses of sand, ash, total organic C, total N, total P, available Zn and exchangeable bases as mentioned earlier under Section 4.3.4.

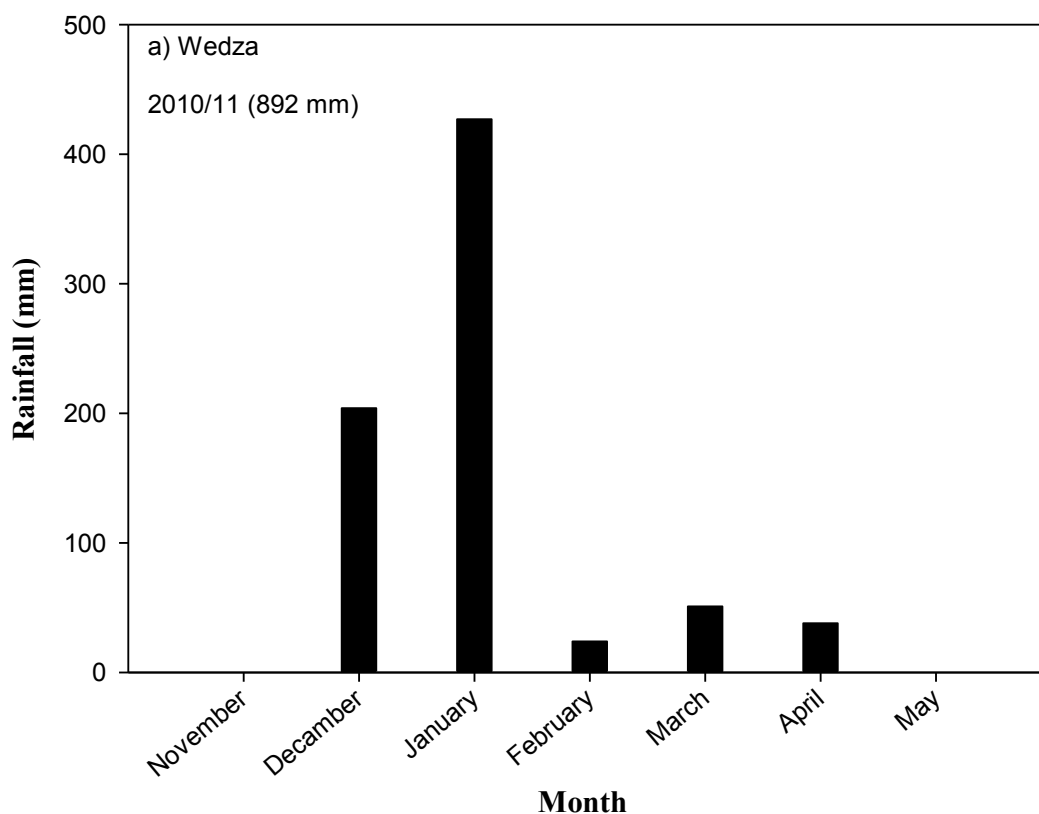
### ***6.3.4 Planting and agronomic management of field site***

Maize SC 513, a medium maturity cultivar, was planted with the first effective rains in November 2009. A crop spacing of 0.9 m x 0.3 m was used giving a population of ~37 000 plants ha<sup>-1</sup>. Ammonium nitrate (34.5% N) was applied at high and low application rates of 90 kg N ha<sup>-1</sup> and 30 kg N ha<sup>-1</sup>, respectively in 3 splits, 30% at 2 WAE, 40% at 6 WAE and 30% at silking. Weeding was done manually using hand hoes, throughout the growing seasons. Maize stalk borer was controlled through thionex (2.5% carbaryl) applied at 3 – 4 kg ha<sup>-1</sup>. During the 2<sup>nd</sup> growing season (2010 – 11), only N, P and K fertilizers were applied with no organic and basal Zn fertilizers. Fertilizer type and composition is as earlier shown in Table 5.2 under Section 5.3.

### ***6.3.5 Maize grain and soil sample collection***

At physiological maturity, samples of maize cob were collected from net plots of 2.7 m x 3.0 m. Soil samples were collected at the end of the 2009 – 2010 cropping season from 5 randomly selected points in each plot to a depth of 0 – 20 cm and mixed thoroughly to form a

composite sample. Cobs were air-dried and shelled manually. Maize grain yield per hectare was then quantified at 12.5% moisture content. Rainfall received during the 2009/10 growing season was presented earlier in Figure 5.1. Figure 6.1 presents rainfall received during the 2010/11 cropping season.



**Figure 6.1** Total rainfall measured in Wedza, eastern Zimbabwe during the 2010/11 cropping season

### **6.3.6 Grain and soil sample preparation and laboratory analysis**

Grain sub samples were ground in a Thomas Wiley Model 4 stainless steel mill to avoid contamination. A sub-sample of grain was withdrawn for each treatment to determine nutrient uptake. The samples were analysed for total Zn and P as described in Section 3.4. Maize grain nutrient uptake was calculated using the formula:

$$\text{Grain nutrient uptake (g ha}^{-1}\text{)} = \text{Grain nutrient concentration (mg kg}^{-1}\text{)} \times \text{grain yield (t ha}^{-1}\text{)}$$

Soil samples were air dried and allowed to pass through a 2 mm sieve. A sub-sample was withdrawn for each treatment and analyzed for N, P, O.C, Zn and exchangeable bases (see Section 3.3).

#### **6.4 Statistical analyses**

Maize grain yield, grain nutrient concentration and nutrient uptake data were examined by analysis of variance (ANOVA) using GENSTAT 13 statistical package. Maize grain yield data was reported at 12.5% moisture content. All mean comparisons were done using the honestly significance difference (HSD) (Tukey's) test at 0.05% significance levels.

#### **6.5 Results**

##### ***6.5.1 Characteristics of the study site***

The site on which the experiment was located had 82% sand content, and classified as loamy sand (Table 6.2). The soil had low mineralizable N and P of 25.0 mg kg<sup>-1</sup> and 5.2 mg kg<sup>-1</sup>, respectively. Total soil organic carbon was 0.45% and the soil is reported to have a moderate amount of organic carbon. The soil was slightly acidic and had EDTA extractable soil Zn content of 1.2 mg kg<sup>-1</sup> which was below the critical value of 1.5 mg kg<sup>-1</sup>. Therefore the soil was considered deficient in Zn. A Ca: Mg ratio of around 1.5 was measured.

**Table 6.2** Physical and chemical characteristics of the soil at site on which the nutrient omission experiment was established

Parameter	Value
Clay (%) <sup>a</sup>	12 (0.3)
Sand (%) <sup>a</sup>	82 (1)
Textural class	Loamy sand
Mineral N (mg kg <sup>-1</sup> )	25.0 (1.2)
Total N (%)	0.06 (0.002)
Available P (mg kg <sup>-1</sup> ) <sup>b</sup>	5.2 (1)
Organic carbon (%)	0.45 (0.04)
pH (0.01 M CaCl <sub>2</sub> )	4.90 (0.15)
EDTA extractable Zn (mg kg <sup>-1</sup> )	1.15 (0.2)
Ca (cmol <sub>c</sub> kg <sup>-1</sup> )	0.8 (0.06)
Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	0.4 (0.01)
K (cmol <sub>c</sub> kg <sup>-1</sup> )	0.1 (0.005)

<sup>a</sup>Hydrometer method; <sup>b</sup>Olsen method. Figures in parentheses denote standard error.

### ***6.5.2 General physico-chemical characteristics of organic nutrient sources applied***

A Sand content of 43% was measured in leaf litter. Cattle manure had the highest sand content of 52% (Table 6.3). The high sand contents maybe attributed to handling of these organic resources. Organic C contents of as high as 31% were measured in leaf litter. In contrast, cattle manure recorded lower organic C contents of around 16%. Nitrogen concentrations averaging 0.7% were measured in both organic nutrient resources. Leaf litter had a P concentration of 0.08% and was not significantly different from 0.06% which was measured in cattle manure. There was a big difference in the amount of Zn contained in these two organic resources where leaf litter had a Zn content of as high as 60 mg kg<sup>-1</sup> DW against 22 mg kg<sup>-1</sup> DW measured in cattle manure (Table 6.3).

**Table 6.3** Nutrient compositions of organic amendments applied to selected treatments

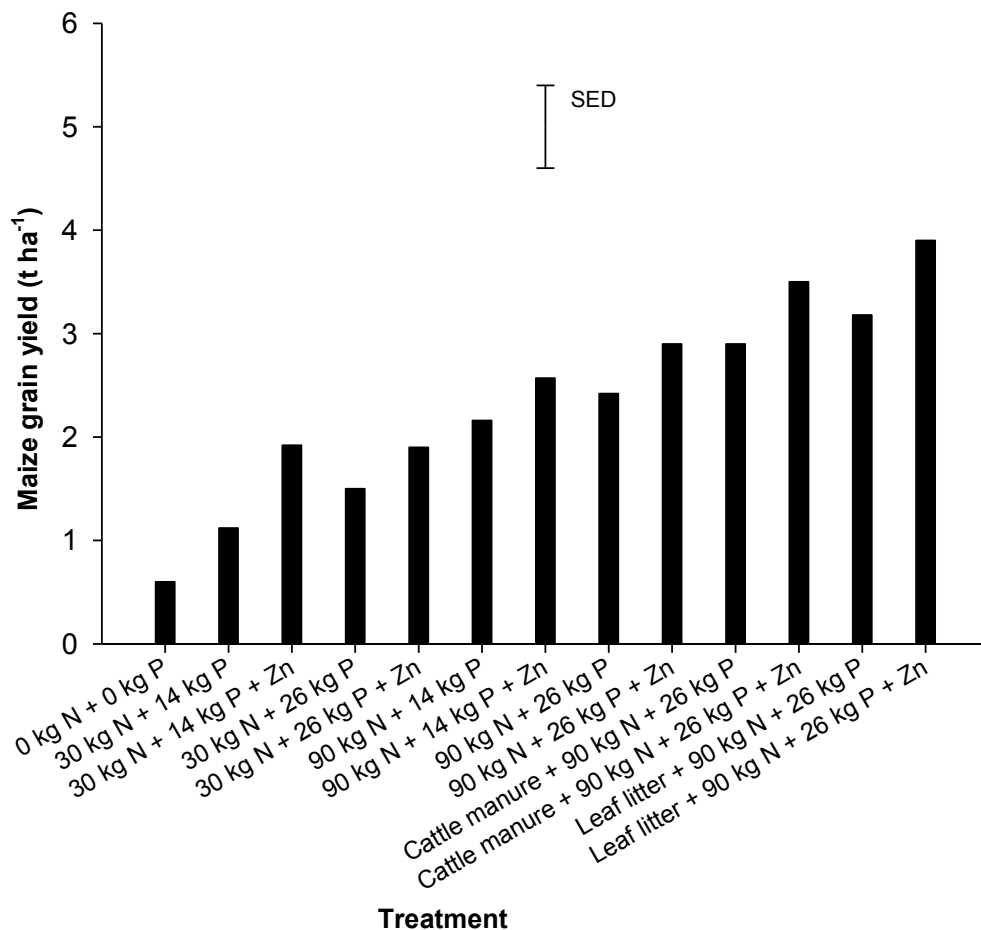
Parameter	Organic amendment	
	Cattle manure	Leaf litter
Sand (%)	52	43
Ash (%)	14.5	19.5
<sup>a</sup> Organic C (%)	15.5	31.4
<sup>b</sup> N (%)	0.71	0.81
C:N	22	39
<sup>c</sup> P (%)	0.06	0.08
<sup>d</sup> Zinc (mg kg <sup>-1</sup> )	22	60
Ca (%)	1.37	1.63
Mg (%)	0.57	0.91
K (%)	0.99	0.87

Procedures by: <sup>a</sup>Walkley-Black method, <sup>b</sup>Kjeldahl procedure, <sup>c</sup>Molybdate – vanadophosphoric acid method, <sup>d</sup>Aqua Regia,

### ***6.5.3 Effect of Zn application on maize grain yield under organic and inorganic fertilizer management***

Significant ( $P < 0.05$ ) maize grain yield differences were observed after application of organic and inorganic fertilizers. Grain yields ranged from 0.8-3.9 t ha<sup>-1</sup> and 0.5-3.0 t ha<sup>-1</sup> during the 2009/10 (Figure 6.2) and 2010/11 (Figure 6.3) cropping seasons, respectively. All organically and mineral fertilized treatments yielded higher yields compared to the absolute control treatment yields. Organic and inorganic combinations measured a maximum of 3.9 t ha<sup>-1</sup>, which was about four-fold higher than the lowest treatment where no fertilizer was applied. During the first year of experimentation, treatments with combinations of mineral and organic fertilizers gave significantly higher yields averaging 3.4 t ha<sup>-1</sup> compared to sole mineral fertilizer treatments which gave an average yield of 2.7 t ha<sup>-1</sup>. Consistently, the highest maize yields were achieved when leaf litter was used in combination with mineral NPK and Zn.

Application of cattle manure produced up to 3.5 t ha<sup>-1</sup> grain yields, and this was comparable to leaf litter.



**Figure 6.2** Maize grain yields after application of Zn in combination with organic and inorganic fertilizers in Wedza, eastern Zimbabwe in the 2009/10 season. SED—Standard error of the difference of means.

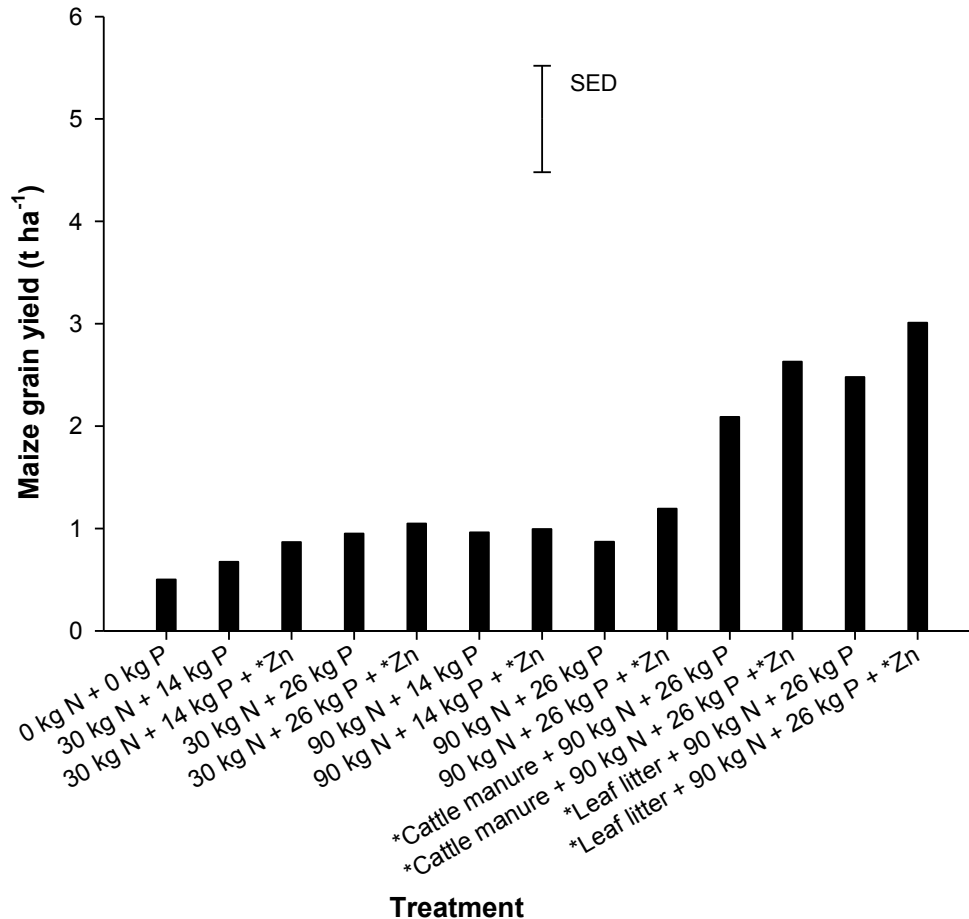
Zinc gave an added yield benefit to both sole mineral and mineral x organic fertilizer combinations. Zinc increased yields by between 11-27% in sole mineral fertilizer and 21-24% in combinations (Figure 6.2). During the first season, there was more added yield benefit after application of Zn in sole mineral fertilizer treatments than in organic fertilizer treatments which already contained Zn. For example, an increase from 1.1-1.9 t ha<sup>-1</sup> was measured in



mineral fertilizer treatments compared to an increase from 2.9-3.5 t ha<sup>-1</sup> in combinations. However, in the second year of experimentation, significantly higher yields were attained in combinations possibly due to enhanced nutrient interactions between mineral fertilizers and residual organic effects (Figure 6.3). A significant reduction in grain yield of >100% and 51% was measured when NPK and NPK and Zn were applied at low rates with respect to high NPK and NPK and Zn counterparts. It was therefore apparent that systematic application of inadequate macronutrient fertilizers with or without Zn would most likely limit grain yields attained on these poor soils.

#### ***6.5.4 Inorganic NPK, Zn and organic fertilizer effects on maize grain Zn concentration***

Maize grain Zn concentration was significantly ( $P < 0.01$ ) influenced by organic and inorganic NPK and Zn fertilizer management. Grain Zn concentrations ranged from 16.1-25.3 mg kg<sup>-1</sup> and 15.4-33.0 mg kg<sup>-1</sup> (Table 6.4) during the 1<sup>st</sup> and 2<sup>nd</sup> year of experimentation, respectively. Application of Zn to both organic and mineral fertilizer treatments yielded superior grain Zn concentrations to the absolute control treatment. Grain Zn concentration increased between 42-88% in sole mineral fertilizers and 103-114% in combinations over the non-fertilized treatment (Table 6.4). Combined application of leaf litter and mineral NPK and Zn fertilizer produced superior grain Zn concentrations of between 25.3- 33.0 mg kg<sup>-1</sup>, and this was not significantly different from the treatment involving combined use of cattle manure and mineral NPK and Zn fertilizer. Consistently, treatments with combinations of organic and inorganic fertilizers gave significantly higher grain Zn concentrations averaging 29.7 mg kg<sup>-1</sup> compared to sole mineral fertilizer treatments which gave an average Zn concentration of 22.6 mg kg<sup>-1</sup> (Table 6.4).



**Figure 6.3** Residual organic and Zn fertility effects on maize grain yields following application of inorganic NPK in the 2010/11 season in Wedza, Zimbabwe. Asterisks indicate treatment where residual fertility was assumed.

On the other hand, there was more added grain Zn benefit after application of Zn in sole mineral fertilizer treatments than in organic fertilizer treatments. For example, an increase between 18-40% was measured in mineral fertilizer treatments compared to an increase of 8-23% in combinations. A significant increase in grain Zn concentration of 28% in sole mineral fertilizers and 30% in combinations was attained when residual Zn effects were tested over concentrations of 22.6 mg kg<sup>-1</sup> and 25.3 mg kg<sup>-1</sup> (Table 6.4) measured in the same treatments, respectively during the first year of experimentation.

Higher concentrations in the 2<sup>nd</sup> year could be related to the much lower grain productivity (Figure 6.3). Application of sole mineral NPK measured a significant increase in grain Zn concentration of 34% over the absolute control treatment. This suggests increased nutrient mining where macronutrients are continuously applied.

**Table 6.4** Zinc concentration and uptake in maize grain measured after application of Zn under organic and inorganic fertilizer management in Wedza, eastern Zimbabwe

Treatment	2009/10		2010/11	
	Grain Zn (mg kg <sup>-1</sup> )	Zn uptake (g ha <sup>-1</sup> )	Grain Zn (mg kg <sup>-1</sup> )	Zn uptake (g ha <sup>-1</sup> )
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>	19.2 <sup>b</sup>	46.5 <sup>bc</sup>	20.7 <sup>b</sup>	18.0 <sup>ab</sup>
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	22.6 <sup>cd</sup>	65.5 <sup>c</sup>	28.9 <sup>cd</sup>	34.5 <sup>b</sup>
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>	18.1 <sup>ab</sup>	20.3 <sup>a</sup>	17.5 <sup>ab</sup>	11.8 <sup>ab</sup>
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	20.4 <sup>bc</sup>	39.2 <sup>b</sup>	21.9 <sup>bc</sup>	19.0 <sup>ab</sup>
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>	20.8 <sup>bc</sup>	53.5 <sup>bc</sup>	23.0 <sup>bc</sup>	22.9 <sup>ab</sup>
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	18.9 <sup>b</sup>	40.8 <sup>bc</sup>	19.8 <sup>b</sup>	19.0 <sup>ab</sup>
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>	21.7 <sup>c</sup>	41.2 <sup>bc</sup>	25.8 <sup>c</sup>	27.0 <sup>b</sup>
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	21.9 <sup>c</sup>	32.9 <sup>ab</sup>	23.1 <sup>bc</sup>	21.9 <sup>ab</sup>
Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>	23.1 <sup>cd</sup>	67.0 <sup>c</sup>	25.4 <sup>c</sup>	53.0 <sup>c</sup>
Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	24.9 <sup>d</sup>	87.2 <sup>cd</sup>	31.3 <sup>d</sup>	82.3 <sup>d</sup>
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>	23.9 <sup>cd</sup>	76.0 <sup>cd</sup>	29.1 <sup>cd</sup>	72.2 <sup>d</sup>
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	25.3 <sup>d</sup>	98.7 <sup>d</sup>	33.0 <sup>d</sup>	99.3 <sup>e</sup>
Absolute control (0 kg N ha <sup>-1</sup> + 0 kg P ha <sup>-1</sup> )	16.1 <sup>a</sup>	9.7 <sup>a</sup>	15.4 <sup>a</sup>	7.7 <sup>a</sup>
Mean	21.3	52.2	24.2	37.6
SED	1.2 <sup>**</sup>	12.5 <sup>**</sup>	1.9 <sup>*</sup>	7.7 <sup>*</sup>
CV (%)	11.7	18.0	12.4	16.3

\* = treatment effect significant at P < 0.05. \*\* = treatment effect significant at P < 0.01. Homogeneous groups are denoted by the same letter. Zinc was applied at a uniform rate of 11 kg ha<sup>-1</sup>. SED - standard error of the differences of means.

#### 6.5.5 Grain Zn uptake as affected by inorganic NPK, Zn and organic fertilizer application

Significant differences in grain Zn uptake were measured among treatments (P<0.05). Overall, maize grain Zn uptake ranged between 9.7-98.7 g Zn ha<sup>-1</sup> and 7.7-99.3 g Zn ha<sup>-1</sup> (Table 6.4) during the 2009/10 and 2010/11 cropping season, respectively. Maize under combined use of leaf litter and inorganic NPK and Zn had superior Zn uptake, yielding up to nine times the

amount taken up under the unfertilized control treatment. Zinc gave an added grain Zn uptake to both sole mineral and mineral and organic fertilizer combinations. However, an increase in grain Zn uptake averaging 48% was attained in sole mineral fertilizer treatments against 30% increase in Zn uptake measured in combinations (Table 6.4). It appears that Zn benefits were significantly expressed in increased Zn uptake compared to increased maize grain yields. For example, there was a 22% increase in grain yield after application of Zn but an increase of up to 34% grain Zn uptake was measured in the same treatment after Zn application (Table 6.5).

**Table 6.5** Added grain yield and Zn uptake benefits following fertilization with different macronutrients and Zn fertilizers in combination with organic nutrient resources

<b>Zinc treatment</b>	<b>Grain yield advantage (%)</b>	<b>Net Zn uptake (%)</b>
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	49.5 (147)	77.0 (225)
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	19.0 (162)	23.5 (288)
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	11.0 (217)	26.0 (324)
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	28.5 (262)	66.5 (462)
Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	23.5 (452)	42.5 (884)
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	22.0 (525)	34.0 (1054)

Zinc was applied at a uniform rate of 11 kg ha<sup>-1</sup>. Values in parentheses denote percent (%) increase with respect to the absolute control treatment.

#### ***6.5.6 Zinc, inorganic NPK and organic fertilizer effects on grain P concentration and uptake***

Significant ( $P < 0.05$ ) differences in maize grain P concentration were observed when P was applied. Grain P concentrations ranged between 0.19–0.33% during the 2009/10 and 0.21–0.34% during the 2010/11 (Table 6.6) cropping seasons. Combined application of organic and inorganic NPK measured superior grain P concentrations of 0.34%, which was significantly different from the lowest treatment by 62%. Application of Zn had a reducing grain P effect to

both sole mineral and mineral and organic fertilizer combinations. Zinc reduced grain P concentration by 13% in sole mineral fertilizers and up to 32% in combinations (Table 6.6). Results suggest that there is a significant decrease in grain P when Zn was co-applied with organic and inorganic fertilizers. Application of sole mineral fertilizers at 90 kg N ha<sup>-1</sup> + 26 kg P ha<sup>-1</sup> resulted in superior grain P concentrations of up to 31% over the low P treatments. The absolute control treatment measured an 11% increase in grain P concentration during the second cropping season.

**Table 6.6** Grain P concentration and uptake following fertilization with macronutrient and Zn fertilizers in combination with organic nutrient resources in Wedza, Zimbabwe

Treatment	2009/10		2010/11	
	Grain P (%)	P uptake (kg ha <sup>-1</sup> )	Grain P (%)	P uptake (kg ha <sup>-1</sup> )
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>	0.28 <sup>c</sup>	6.8 <sup>c</sup>	0.31 <sup>bc</sup>	2.7 <sup>b</sup>
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	0.26 <sup>bc</sup>	7.5 <sup>c</sup>	0.29 <sup>bc</sup>	3.5 <sup>b</sup>
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>	0.24 <sup>bc</sup>	2.7 <sup>ab</sup>	0.26 <sup>ab</sup>	1.8 <sup>ab</sup>
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	0.22 <sup>ab</sup>	4.2 <sup>b</sup>	0.25 <sup>ab</sup>	2.2 <sup>ab</sup>
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>	0.21 <sup>ab</sup>	5.4 <sup>bc</sup>	0.25 <sup>ab</sup>	2.5 <sup>ab</sup>
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	0.23 <sup>b</sup>	5.0 <sup>bc</sup>	0.27 <sup>b</sup>	2.6 <sup>ab</sup>
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>	0.24 <sup>bc</sup>	4.6 <sup>b</sup>	0.27 <sup>b</sup>	2.8 <sup>b</sup>
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	0.27 <sup>c</sup>	4.1 <sup>b</sup>	0.29 <sup>bc</sup>	2.8 <sup>b</sup>
Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>	0.30 <sup>cd</sup>	8.7 <sup>cd</sup>	0.33 <sup>c</sup>	6.9 <sup>c</sup>
Cattle manure + 26 P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	0.25 <sup>bc</sup>	8.8 <sup>cd</sup>	0.30 <sup>bc</sup>	7.9 <sup>cd</sup>
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>	0.33 <sup>d</sup>	10.5 <sup>d</sup>	0.34 <sup>c</sup>	8.4 <sup>cd</sup>
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	0.25 <sup>bc</sup>	9.8 <sup>d</sup>	0.31 <sup>bc</sup>	9.3 <sup>d</sup>
Absolute control (0 kg N ha <sup>-1</sup> + 0 kg P ha <sup>-1</sup> )	0.19 <sup>a</sup>	1.2 <sup>a</sup>	0.21 <sup>a</sup>	1.1 <sup>a</sup>
Mean	0.25	6.1	0.28	4.2
SED	0.01 <sup>*</sup>	1.1 <sup>*</sup>	0.02 <sup>*</sup>	0.8 <sup>*</sup>
CV (%)	13.1	12.6	14.3	14.9

\* = treatment effect significant at P < 0.05. Means followed by the same letter are not significantly different.

Overall, maize grain P uptake ranged between 1.2 to 10.5 kg ha<sup>-1</sup> during the 1<sup>st</sup> season (Table 6.6), while values between 1.1 to 9.3 kg P ha<sup>-1</sup> were obtained during the 2<sup>nd</sup> year of experimentation (Table 6.6). Significant differences were measured among treatments (P < 0.05) with treatment involving combined use of leaf litter and inorganic fertilizers

consistently yielding superior P uptake of up to eight times the amount taken up under the unfertilized control treatment. Results indicate the significance of organic materials in supplying multiple nutrients including P for increased nutrient uptake. Application of Zn resulted in reduced grain P concentration. However, increased P uptake on treatments with Zn was possibly due to increased grain yields after Zn fertilization.

#### ***6.5.7 Plant available soil Zn and P as influenced by Zn application under organic and inorganic fertilizer management***

Application of Zn under organic and inorganic fertilizer management only exhibited significant ( $P < 0.05$ ) effects on available soil Zn and P, with no influence on all other measured soil chemical parameters (Table 6.7). Plant available soil Zn ranged from 0.97-5.48 mg kg<sup>-1</sup>. Consistently, soils collected from treatments with combinations of mineral and organic fertilizers gave superior available soil Zn concentrations averaging 3.6 mg kg<sup>-1</sup> compared to soils from sole mineral fertilizer treatments which gave an average soil Zn concentration of 1.8 mg kg<sup>-1</sup>.

Application of Zn resulted in build-up of available soil Zn to both sole mineral and mineral and organic fertilizer combinations. Increases in plant available soil Zn ranged between 1.75-2.75 mg kg<sup>-1</sup> in sole mineral fertilizers and 2.33-5.48 mg kg<sup>-1</sup> in combinations (Table 6.7). An increase of 37% plant available soil Zn measured from treatments with leaf litter over cattle manure treatments was attributed to higher available Zn concentrations of 60 mg kg<sup>-1</sup> in leaf litter compared to concentrations of 22 mg kg<sup>-1</sup> measured in cattle manure samples. The field had a gradient of < 2% therefore erosion, leaching and plant uptake were assumed to be the

same. This left the seasonal input of organic nutrient resources as the most likely cause of differences in Zn.

Consistently, soils collected from the non-fertilized treatment had the lowest Zn concentrations of  $<1.0 \text{ mg kg}^{-1}$ . On the other hand, available soil P was consistently low, ranging from  $5.0 \text{ mg kg}^{-1}$  in the absolute control treatment to  $6.5 \text{ mg kg}^{-1}$  for treatments receiving combinations of leaf litter and mineral fertilizer (Table 6.7). However, highest available P concentrations measured in leaf litter treatments were not significantly different from treatments which received cattle manure. Overall, the absolute control treatment resulted in a decrease of  $\sim 19\%$  in available soil Zn and  $4\%$  in available soil P from the initial nutrient concentration of about  $1.2 \text{ mg Zn kg}^{-1}$  and  $5.2 \text{ mg P kg}^{-1}$  (Table 6.7).

**Table 6.7** Soil chemical properties measured during the 2009/10 cropping season after 1<sup>st</sup> application of organic and inorganic fertilizer combinations

Treatment	Parameter						
	Available Zn (mg kg <sup>-1</sup> )	Available P (mg kg <sup>-1</sup> )	N (%)	O.C (%)	Ca	Mg cmol c kg <sup>-1</sup>	K
<b>Initial nutrient concentration</b>	<b>1.15</b>	<b>5.2</b>	<b>0.06</b>	<b>0.45</b>	<b>2.89</b>	<b>1.91</b>	<b>0.30</b>
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>	1.19 <sup>ab</sup>	5.9 <sup>bc</sup>	0.07	0.45	2.41	1.97	0.29
90 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	2.75 <sup>b</sup>	5.9 <sup>bc</sup>	0.06	0.47	2.55	1.34	0.27
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>	1.27 <sup>ab</sup>	5.4 <sup>ab</sup>	0.05	0.43	2.33	1.27	0.28
30 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	2.32 <sup>b</sup>	5.6 <sup>b</sup>	0.06	0.43	2.33	1.94	0.27
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup> + Zn	2.57 <sup>b</sup>	5.8 <sup>bc</sup>	0.07	0.40	2.45	1.88	0.29
90 kg N ha <sup>-1</sup> + 14 kg P ha <sup>-1</sup>	1.45 <sup>ab</sup>	5.1 <sup>ab</sup>	0.05	0.46	2.57	1.61	0.26
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup> + Zn	1.75 <sup>ab</sup>	5.5 <sup>b</sup>	0.06	0.42	2.52	1.92	0.26
30 kg N ha <sup>-1</sup> + 26 kg P ha <sup>-1</sup>	1.12 <sup>ab</sup>	5.5 <sup>b</sup>	0.04	0.43	2.69	1.25	0.30
Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>	2.33 <sup>b</sup>	6.2 <sup>c</sup>	0.07	0.49	2.41	1.48	0.31
Cattle manure + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	4.02 <sup>c</sup>	6.1 <sup>c</sup>	0.06	0.51	2.52	1.21	0.29
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup>	2.60 <sup>b</sup>	6.2 <sup>c</sup>	0.08	0.50	2.87	1.56	0.29
Leaf litter + 26 kg P ha <sup>-1</sup> + 90 N ha <sup>-1</sup> + Zn	5.48 <sup>d</sup>	6.5 <sup>c</sup>	0.09	0.48	2.92	1.01	0.30
Absolute control (0 kg N ha <sup>-1</sup> + 0 kg P ha <sup>-1</sup> )	0.97 <sup>a</sup>	5.0 <sup>a</sup>	0.05	0.45	2.83	1.45	0.28
SED	0.6 <sup>*</sup>	0.2 <sup>*</sup>	0.04 <sup>ns</sup>	0.25 <sup>ns</sup>	0.60 <sup>ns</sup>	0.45 <sup>ns</sup>	0.05 <sup>ns</sup>

\* means significant differences measured at P<0.05, ns = no treatment differences recorded at P<0.05. Zinc was applied at a uniform rate of 11 kg ha<sup>-1</sup>.



## 6.6 Discussion

### *6.6.1 Maize grain yield under Zn application and organic and inorganic fertilizer management*

Combined use of organic and inorganic fertilizers gave superior maize grain yields compared to sole mineral fertilizer treatments regardless of type of organic nutrient resource. Application of organic and inorganic fertilizers to maize is a common soil fertility management practise in smallholder farming systems in Zimbabwe (Mapfumo and Giller, 2001) and has proved to be a major source of yield benefits. The commonly applied organic resources include animal manure, woodland litter and composts (Mapfumo, 2006).

High yields achieved after co-application of organic and inorganic fertilizers could be due to increased nutrient use efficiency, water holding capacity and microbial activity (Palm et al. 1997; Nhamo et al., 2004; Chikowo et al., 2010). Organic fertilizers have also been found to result in increased solubility and uptake of P from sparingly soluble P compounds in the soil thus enhanced utilization of P from fertilizers (Iyamuremye and Dick, 1996; Cakmak, 2002). In the process, root density is increased and this in turn improves plant growth. Improved maize grain yields derived from combined use of organic and mineral (inorganic) nutrient resources under similar climatic conditions in Zimbabwe have been quantified (Zingore, 2006).

Inherently low stocks of Zn in the soil limited crop growth in sole mineral fertilizer treatments to the extent that application of Zn resulted in added yield benefits. Apart from benefits attained from application of organic resources, Zn had an added yield benefit in combinations compared to sole mineral fertilizers suggesting Zn significantly enhances nutrient interactions when co-applied with organic and inorganic fertilizers. Lack of such interactions where Zn

was applied in sole mineral fertilizers might have resulted in a higher drop in yields compared to a drop in yields measured in combinations. Significantly improved grain yields attained after application of Zn in combination with organic and inorganic NPK fertilizers compared to yields attained in farmers' fields imply ISFM options as currently presented to smallholder farmers should be supplemented with Zn. Although the study did not address the economic analysis, estimates from this study revealed that the additional cost of purchasing a Zn containing fertilizer is only \$2.00 (data not shown), but the added yield benefit exceeds 1.6 t ha<sup>-1</sup>. Possibility of addition of other micronutrients should also be looked at. On the other hand, more grain yields attained under organic and inorganic fertilizer combinations effectively imply more Zn should be applied to balance off Zn deficits.

Results from this study also showed that different application rates of N and P significantly improve maize yield. Grain yield was significantly higher with application rates of 90 kg N ha<sup>-1</sup> + 26 kg P ha<sup>-1</sup> + Zn compared to lower NPK application. As most smallholder farms are inherently deficient in essential macro- and micro-nutrients, application of adequate levels of N and P is important if significantly improved yields are to be obtained. It is therefore important to maintain high soil N and P fluxes so as to attain high yields (Mtambanengwe, 2006). While findings from this study proved that Zn application under organic and inorganic fertilizer management significantly increased maize grain yields, there is need for information dissemination so that farmers can implement such soil fertility management practices in their fields.

#### ***6.6.2 Influence of Zn application and organic and inorganic fertilizers on maize grain nutrient concentration and uptake***

Overall, maize grain Zn concentration was significantly improved by combined use of organic

nutrient resources and mineral fertilizer. Notably, grain Zn concentration was higher in maize grown under combined use of woodland leaf litter and inorganic fertilizers than the other treatments. Organic matter has been found to be one of the most important factors affecting availability of Zn to plants through formation of soluble organic complexes which are mobile and capable of absorption into plants (Prasad, 1999; Alloway, 2004). Therefore, it is important to apply different organic nutrient resources for improved Zn nutrition. Previous studies by Verma and Panday (2008) also showed that combined use of vermi-compost and inorganic NPK and Zn fertilizers can improve Zn concentration and uptake in lentil plants (*Lens culinaris medic*).

Application of soluble ZnSO<sub>4</sub> either as sole mineral fertilizer or in combination with organic resources appears to be a viable option for improved maize grain Zn concentration. However, results indicated that more grain Zn was obtained following sole mineral Zn- based fertilizers compared to organic nutrient resources possibly because there was a buffering effect on external Zn applied caused by Zn already contained in organic resources. Zinc which is applied in sole mineral fertilizer treatments directly feeds into the soil and translates to improved grain quality. To realize the same increase in grain quality under combinations of organic and inorganic fertilizers, there might be a need to apply more Zn so as to reduce buffering capacity of Zn inherently available in organic resources. Although farmers who apply sole mineral fertilizers have more benefits in terms of percent increase in grain quality, they need to consistently apply Zn because values attained under such management do not meet required thresholds. However, the disadvantage of this soil fertility management practice is that not all farmers are able to continuously supply Zn hence becomes unsustainable.

Results also showed that there is potential of long Zn supply in organics than in sole mineral fertilizers suggesting a reduced demand for Zn by farmers who use combinations of organic

and inorganic fertilizers. This result is also supported by improved grain yields under residual organic fertility compared to residual Zn in sole mineral fertilizers. Although smallholder farmers can still benefit from long term application of organic nutrient resources, there is still need for external Zn fertilization due to insufficient amounts in commonly used organic resources (Manzeke et al., 2012). It was however important to note that effect of Zn was more pronounced when measured in uptake than in yield.

Treatments without external Zn fertilizers enhanced Zn uptake and this suggests current fertilizer management practices by farmers promote Zn mining and are likely to result in long-term severe deficiencies in soils. Several studies have shown negative nutrient balances which characterize most smallholder farms as the levels of nutrient inputs are often too low to offset nutrient mining (Smaling et al., 1997; Bekunda and Manzi, 2003). Superior P concentrations were measured in grain produced under combined use of organic and inorganic fertilizers. On the other hand, application of Zn significantly reduced grain P concentration. While several authors have reported Zn-P antagonistic relationships (Kovacevic et al., 2008), influence of Zn on P uptake under such soil fertility management studies had remained largely unexplored.

### ***6.6.3 Influence of Zn application and organic nutrient resources on plant available soil Zn and P status***

Application of Zn in combination with organic and inorganic fertilizers significantly improved available soil Zn and P. High initial nutrient concentrations of 60 mg kg<sup>-1</sup> measured in leaf litter seemed to significantly increase available soil Zn. Studies conducted by Muller – Samann and Kotshi (1994) showed the capacity of savanna miombo tree species to scavenge for nutrients from deeper soil horizons which therefore could be potential sources of Zn. Use of ZnSO<sub>4</sub> proved a possible avenue for improving plant available soil Zn as indicated by high

EDTA- extractable soil Zn concentrations above the critical value of  $1.5 \text{ mg kg}^{-1}$  on treatments that received external Zn fertilization. The effectiveness of  $\text{ZnSO}_4$  in increasing Zn availability in agricultural soils is mainly due to its high solubility over other Zn compounds as has been reported earlier (Tagwira, 1991; Cakmak et. al., 1999). Zinc application solely or in combination with organic nutrient resources on granite derived sandy soils seems therefore a promising approach to improve Zn availability. Katyal and Randhwa (1983) reported a 37% increase in available soil Zn after continuous cropping with organic amendments, whereas without them, the initial available Zn was reduced.

Application of organic and inorganic fertilizers significantly increased available soil P. Highest available soil P concentrations measured in leaf litter treatments suggest leaf litter adds more P to the soil compared to cattle manure. During decomposition, leaf litter produces organic acids and humic substances which result in increased nutrients, including P in the soil (Mengel and Kirkby, 1987; FAO, 2004). Although organic residual fertility is known to last for years (Traore, 2006), results of available soil P from the study were low. Granite derived sandy soils under smallholder production are inherently deficient in P among other nutrients (Grant 1981; Mashiringwani, 1983) suggesting a need for adequate, continuous external P fertilization for improved soil nutrition and crop productivity.

## **6.7 Conclusions**

The results showed that combined use of organic and inorganic fertilizers significantly increased grain yields. Although use of locally available organic resources resulted in improved grain yields, ISFM will most likely be undermined by lack of micronutrients which should be systematically used to ameliorate inherently Zn deficient soils. While there is a reduced demand for Zn in management based on organic than mineral fertilizers, use of

locally available organic nutrient resources provides an opportunity for farmers to apply more Zn- based fertilizers to build soil Zn stocks. Although application of Zn in sole mineral fertilizers gave more grain quality benefits compared with their combinations, fields receiving sole mineral fertilizers have a demand for Zn which is greater than those where combinations of organic and inorganic fertilizers are used. Current fertilizer management practices by farmers exacerbate Zn mining and are likely to promote long term severe deficiencies in soils. It is therefore imperative that options such as combined use of Zn-containing mineral fertilizers and organic nutrient resources are consistently employed for improved grain yields and quality. Further empirical research on effect of Zn application on P uptake is warranted.

## Chapter 7

### Overall discussion, conclusions and recommendations

#### 7.1 Micronutrients and their role in plant nutrition

Micronutrients are required in small quantities for plant growth and their dominant role is as activators in numerous enzyme systems of plants (Brady and Weil, 2002). As Liebig illustrated in the concept of a balanced diet of crop nutrients, the potential yield of a crop is limited by nutritional deficiencies or imbalances of either macro- or micronutrients ([www.aglearn.net](http://www.aglearn.net)). Apart from Liebig's law, Mitscherlich's law of the minimum also apply in crop production. A small amount of micronutrients can therefore have the same effect on yield as large quantities of macronutrients. The availability of essential micronutrients for plant growth such as Cu, Fe, Mn and Zn is a critical factor in a plant's response to macro- and micronutrients. For example, inadequacies in molybdenum are associated with deficiencies in N and Cu implying synergy among these nutrients. Severe cases of Zn deficiency in maize are broad band of chlorotic tissue on one or both sides of leaf midrib, striping of leaves, delayed maturity and reduced yields (Alloway, 2004). To remedy this, management of fertility which includes external supply of Zn to these soils is required to impact positively on both plant and human nutritional security.

Copper, Fe and Zn deficiencies are known to limit maize growth on sandy soils under some rain-fed systems in Zimbabwe (Grant, 1981, Mukurumbira and Nemasasi, 1997). This may also result in compromised food and nutrition security for many farming households. As human nutrition in smallholder communities is largely depended on cereals derived from these soils, external fertilization is important to improve Zn content of such crops and combat

complications associated with malnutrition. Zinc fertilization is also important to avoid differential contents of soil micronutrients due to continuous use of soil.

## **7.2 Problem of low zinc stocks in Zimbabwe**

The main factor determining the amount of nutrients in the soil is the parent material that underpins soil formation processes. Inherent soil Zn deficiency in Zimbabwe is mainly due to poor availability of the nutrient in the predominantly granite parent rock (Grant, 1981). The total Zn concentration in granite rocks is as low as  $48 \text{ mg kg}^{-1}$ . Granite derived coarse sands constitute about 40% of cropped areas in the smallholder sector in Zimbabwe (Tagwira, 1991) and typical of such areas were Gutu, Murehwa, Mutoko and Wedza communal areas. In contrast, the basalt and dolerite rocks have high Zn concentrations of up to  $100 \text{ mg kg}^{-1}$ . However, soils derived from these parent materials only constitute about 13% of cropped land in these farming systems. They are only dominant in areas such as Guruve and Gwebi. Apart from the parent material, soil texture also plays a key role in micronutrient availability. With most communal areas in Zimbabwe dominated by granite coarse sands, it is therefore likely that the large majority of the farms are deficient in Zn compared with the red clay soils derived from basalt rocks.

Observed differences in soil fertility could only be attributed to farmer soil fertility management practices. Findings from a soil fertility survey conducted in two different agro-ecological regions used in this study indicated that most smallholder farms were inherently deficient in Zn. Management practices which include removal of crop residues after harvest and high dependence on macronutrient-containing fertilizers are likely to exacerbate soil Zn deficiencies. The problem of Zn deficiency in humans is mainly referred to as hidden hunger because losses in maize grain yield are minimum on fields which receive external fertilization



but nutritional composition of harvested grain is low ([www.harvestplus.org](http://www.harvestplus.org)). This implies that although people may be food sufficient, they suffer silently from lack of adequate Zn in their diets.

### **7.3 Influence of farmer soil fertility management on zinc status and distribution**

One of the objectives of the study was to determine the influence of farmer soil fertility management regimes on soil Zn distribution. Management regimes currently used by smallholder farmers include use of organic nutrient resources such as cattle manure and woodland litter in combination with mineral fertilizers, legume-cereal rotations and sole mineral fertilizers. The option of co-applying organic nutrient resources with mineral fertilizers effectively improved grain yields to about 2.3 t ha<sup>-1</sup> in contrast to the non-fertilized maize which yielded <0.5 t ha<sup>-1</sup> (Chapter 4; Manzeke et al., 2012).

Within fields and farms, gradients in fertility are created due to different farmer management practices (Mtambanengwe and Mapfumo, 2005; Tittonell et al., 2005). In this study, farmers who applied locally available organic nutrient resources which include woodland litter and cattle manure managed to significantly improve grain and available soil Zn concentrations. Use of legume-based rotations also significantly improved grain Zn content. While farmers are aware of importance of legumes in fixing atmospheric N<sub>2</sub>, it is important to raise awareness on superiority of legumes that include groundnut and cowpea, to scavenge for nutrients in soils and enhance their cycling.

Although use of organic nutrient resources and legume-cereal rotations emerged as potential sources of Zn, grain Zn concentrations were below the recommended amounts of 40-60 mg kg<sup>-1</sup> (Pfeiffer and McClafferty, 2007). It might be insufficient to depend on these management practices if adequate grain Zn levels are to be realized. This, therefore, calls for the need to

systematically use Zn-containing mineral fertilizers in combination with the current farmer soil fertility management resources to avoid health complications associated with Zn malnutrition. Further research may however be warranted to assess the dietary composition of other foods consumed by smallholder farmers so as to realize their nutritional contribution towards improving Zn nutrition.

#### **7.4 External Zn application as a critical factor for improved grain quality**

The problem of soil Zn deficiency currently observed in smallholder areas of Zimbabwe demands for a drastic change in the formulation and management of fertilizers used by farmers. Existing farmer soil fertility management practices are insufficient to improve maize grain Zn concentrations. In this study, combined use of basal and foliar Zn fertilizers improved grain Zn concentration to 39 mg kg<sup>-1</sup> compared to 18 mg kg<sup>-1</sup> measured without Zn fertilization. Sole foliar fertilization also gave comparable grain Zn concentration to combinations of basal and foliar Zn, but adoption of this management option at smallholder farmer level maybe compromised by lack of technical know-how as well as its demands on labour. Foliar fertilization is likely to be practical in the area of horticulture which has high returns, making it possible for the farmer to seasonally apply foliar fertilizers. On the other hand, combined use of basal and foliar Zn fertilizers might also be expensive to the smallholder farmer who often fails to apply macronutrient-containing fertilizers due to lack of purchasing power. Therefore, a practical and economically viable option for the financially constrained smallholder farmer is application of sole basal Zn fertilizers which result in improved grain Zn concentration as well as residual fertility benefits.

Findings from the study justify and recommend biofortification of staple maize through use of Zn containing fertilizers for improved grain yields and quality. Researchers should therefore

engage fertilizer companies and other agro-service providers such as extension to enable the much needed information available to farmers. As Zn availability is also influenced by crop type and variety (Alloway, 2008), further research to determine Zn extraction efficiency of different maize varieties produced by local seed companies is warranted.

### **7.5 Use of organic and inorganic fertilizer combinations for improved grain yields and quality**

The main pillar of ISFM is combined use of organic nutrient resources and inorganic fertilizers for improved grain yields. On the other hand, organic nutrient resources locally available to smallholder farmers are a potential source of Zn. Farmers who applied leaf litter and cattle manure managed to significantly improve grain Zn concentration and available soil Zn compared to those who applied sole mineral NPK fertilizers (Chapter 4; also see Manzeke et al., 2012). However, the potential nutrient supply capacity of these organic resources proved insufficient to effectively meet the demands for improved grain quality.

Results from the study showed that there is a possibility of improved maize grain yields if combinations of organic and inorganic fertilizers are used with Zn-based fertilizers. This implies that benefits of ISFM could be compromised severely by lack of micronutrients such as Zn. Application of organic and inorganic NPK and Zn fertilizers also significantly improved grain quality. However, farmers who apply sole mineral fertilizers could have a demand for Zn which is greater than those who co-apply organic nutrient resources and inorganic fertilizers. Combined application of organic and inorganic fertilizers also has potential benefits of supplying residual fertility to the subsequent maize crop suggesting that if soil is supplied with available forms of nutrients, farmers could benefit beyond one season.

To avoid Zn mining associated with current smallholder farmer soil fertility management practices, there is a need for external application of Zn-containing fertilizers. Smallholder farmers usually adopt a new technology if there are yield benefits associated with it. Results from the study showed that the strategy of applying Zn-based mineral fertilizers in combination with nutrient resources addressed both yield and grain quality benefits. Therefore, disseminating such knowledge to smallholder farmers is unlikely to be a challenge due to the food and human nutrition security linked with Zn application. Players in fertilizer manufacturing could also assist by producing compound Z in smaller packs (<50 kg) which may be more affordable to the farmer.

#### **7.6 Implications of current fertilizer policies on micronutrient management in Zimbabwe**

Until recently, policy debates about the fertilizer sector in African countries focused particularly on subsidies and macroeconomic management giving little attention to issues of research investments. In Zimbabwe, few studies have shown distribution of subsidized NPK fertilizers by the Government through state agencies such as Grain Marketing Board (GMB) (FAO, 2006; Minde et al., 2010). Apart from subsidies, donor and lending agencies have also been providing fertilizers to the smallholder farmers. Subsidised or donated fertilizers distributed in smallholder maize production systems in Zimbabwe do not contain essential micronutrients such as Zn. Unlike in production of cotton fertilizer where manufacturing companies are only licensed if they produce compound fertilizer with boron (B), it is currently not mandatory for fertilizer manufacturers to incorporate Zn in maize fertilizers. Sufficient buy-in from the government and relevant policy makers could contribute to enhanced Zn nutrition through maize production.

Currently, lack of knowledge among farmers on the importance of Zn fertilizers has a negative feedback on supply from manufacturers. For the fertilizer sector to produce micronutrient-containing fertilizers, the Government in consultation with the relevant stakeholders could develop a national fertilizer sector policy which ensures incorporation of Zn in maize fertilizer formulations and promote production of such fertilizers on a larger scale. To boost fertilizer demand, policies that strengthen farmers' capacity to acquire fertilizers, increase their knowledge on micronutrient-fertilizer use and promote investment in agricultural research and extension are needed.

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## APPENDICES

### Appendix 1 List of publications from this thesis

1. **Grace M. Manzeke**, Paul Mapfumo, Florence Mtambanengwe, Regis Chikowo, Takesure Tendayi and Ismail Cakmak. 2012. *Soil fertility management effects on maize productivity and grain zinc content in smallholder farming systems of Zimbabwe*. Plant and Soil. 361: 57-69.
2. **Grace M. Manzeke**, F. Mtambanengwe, P. Mapfumo, R. Chikowo, and I. Cakmak. 2011. *Maize productivity and grain zinc and phosphorus nutritional value as affected by different soil fertility management practices in smallholder farming systems in Zimbabwe*. Abstract presented at the 10th African Crop Science Society (ACSS) Conference on “**From Soil to Soul: Crop Production for Improved African Livelihoods and a Better Environment for Future Generations**”. Maputo, Mozambique. pp 267-268.
3. **Manzeke Grace**, Chikowo Regis, Mtambanengwe Florence, Cakmak Ismail, Mapfumo Paul. 2011. *Evaluating the Potential of Zinc-Containing Fertilizers for Improved Production and Zinc Nutrition of Maize Grain in Zimbabwe*. Abstract presented at the 3<sup>rd</sup> International Zinc Symposium on “**Improving Crop Production and Human Health**”. Hyderabad, India, 10 – 14 October 2011.
4. **G.M. Manzeke**, F. Mtambanengwe, G. Kanonge, R. Chikowo, P. Mapfumo. 2012. *Zinc fertilization, maize productivity and grain quality under integrated soil fertility management in smallholder farming*. Abstract presented at the Integrated Soil Fertility Management (ISFM) Africa Conference: “**From Microbes to Markets**”. Nairobi, Kenya, 22 – 26 October 2012.

### Award from the Thesis data

3rd best **Poster Presentation** award at the 3rd International Zinc Symposium held from the 10<sup>th</sup> – 14<sup>th</sup> October 2011 in Hyderabad, India.

**Appendix 2** The participatory rural appraisal checklist used in Wedza and Makoni Communal Areas, Zimbabwe

**Knowledge and use of locally available organic resources in the Goto and Nyahava wards of Wedza and Makoni communal areas**

**PRA Checklist**

**1. Nutrient resources**

Range and availability of organic nutrient resources within and around farm  
Accessibility of these organic nutrient resources  
Understanding of importance of organic resources  
Do farmers use these locally available organic resources? If yes, which one and why?  
On which crops do you apply these organic resources?

**2. Understanding and use of Integrated Soil Fertility Management (ISFM)**

Do you apply organic resources in combination with mineral fertilizers to maize/ how do you use identified ISFM options in your fields?  
If yes why? For improved yields, soil fertility etc.  
How much organics do you apply and how often?  
Which mineral fertilizers do you combine with organic resources?  
Do you understand the concept of legume-cereal rotations? (same land size and good legume ground cover).  
Grain legumes grown and their importance  
Do you fertilize legumes?  
Which fertilizers do you use for legume fertilization?  
Any field you plant and fail to apply any fertilizers?  
How often do you fail to fertilize your maize fields and reasons for failure?

**3. Management of organic resources**

How do you prepare organic resources before planting?  
What time do you prepare your fields?  
Reasons for failure to prepare on time  
When do you place organic resources in your fields?  
How do you apply organic resources (e.g. broadcasting, banding, or placement per planting station?)

How do you manage crop residues? (e.g. place in cattle kraal, burning or as cattle feed).

If you were to get organic resources, were you going to apply less or the recommended amount of mineral fertilizer to maize?

#### **4. Understanding of nutrient deficiencies and possible solutions**

Any nutrient deficiency you observe on maize?

Possible causes of nutrient deficiencies and ways to ameliorate them.

Understanding of zinc as a micronutrient (explain to farmers inherent deficiency and importance of Zn to plants and humans).

Identification of zinc deficiency

Any zinc containing fertilizer you know of?

Understanding and importance of soil sampling when one notices any nutrient deficiency

Understanding of maize grain sampling (only to selected farmers in each fertility domain)