RESPONSE OF COWPEA TO VARIABLE RATES AND METHODS OF ZINC APPLICATION UNDER RAINFED AND SUPPLEMENTARY IRRIGATION CONDITIONS

by

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DEDICATION

I dedicate this mini-dissertation to my beloved parents Salome and Mogotlo Moswatsi for their financial support, love and guidance throughout my studies.

DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Agriculture (Agronomy) has not previously been submitted by me for a degree at this or any other university; that it is my work is design and in execution, and that all material contained herein has been duly acknowledged.

Moswatsi, MS (Ms)	**10 April 2015**
Surname, Initials (title)	**Date**

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ABSTRACT

Agronomic field trial was planted at two sites, Ukulima and Syferkuil, in Limpopo Province, to determine the response of cowpea to variable rates and methods of zinc application under supplementary irrigation and rainfed conditions, respectively. The experiment was laid out in a split plot arrangement and fitted into a randomized complete block design (RCBD). Treatments consisted of two factors namely zinc rates (0, 5, 10, 15, 20 and 25 kg ha^{-1}) and methods of application (soil and foliar) with white cowpea variety (IT00K-1217) seeds sown. The zinc fertilizer was applied as $ZnSO_4$ (38.5% Zn) while basal phosphorus (30 kg P ha^{-1}) was applied in the form of single super phosphate (10.5% P) so as to eliminate P constraints. Soil application of the zinc fertilizer was band placed near the row of cowpea plant while foliar application was done 3-5 weeks after plant emergence. Growth parameters measured included plant height, number of primary branches, canopy cover, number of trifoliate leaves, days to 50% flowering and pod formation, and fresh biomass as well as yield component attributes. Twenty young cowpea leaves and immature green pods were each harvested at approximately 75% physiological maturity. Crude protein, total nitrogen, potassium, phosphorus, zinc, and iron content and uptake were assessed in the different plant parts. Growth, yield and nutrients data collected were subjected to analysis of variance. Treatments means were separated using Tukey's test at probability level of 5%, while the response variables were modelled using quadratic polynomial equation.

Results obtained revealed that total above ground biomass yield of 6219 kg ha^{-1} and fresh pod weight of 142.3 g were obtained when zinc was soil applied under rainfed condition compared to 6019 kg ha^{-1} and 138.0 g for total above ground biomass yield and fresh pod weight, respectively when foliar applied. Soil application gave a total above ground biomass yield of 6298 kg ha^{-1} and pod fresh weight of 150.9 g while foliar application gave total above ground biomass yield and pod fresh weight of 4791 kg ha^{-1} and 124.0 g, respectively at Ukulima. Soil application also gave a significantly higher grain yield (2251 kg ha^{-1}) than the foliar application (1503 kg ha^{-1}) at Ukulima. A higher but inconsequential effect on grain yield was obtained with soil over foliar application at Syferkuil. Application of zinc fertilizer at a rate beyond 5 kg ha^{-1} resulted in a grain yield reduction of up to 22.2% and 6.6% respectively at

Ukulima and Syferkuil. Thus, this rate appeared optimum for both grain and fodder production when soil applied at both sites. Based on the quadratic model, total biomass (4897 kg ha^{-1}) and grain (1602 kg ha^{-1}) yields were optimized at an estimated zinc rate of 54.7 and 33.4 kg ha^{-1}, respectively under supplementary irrigation, while total biomass (5913 kg ha^{-1}) and grain (2696 kg ha^{-1}) yields were obtained at an estimated optimum zinc rate of 20.1 and 26.8 kg ha^{-1}, respectively under rainfed condition. A scorching effect of cowpea leaves was observed following foliar application of zinc fertiliser at 25 kg ha^{-1} that resulted in a decreased growth and yield at Ukulima. Foliar application resulted in improve cowpea leaf zinc concentration (43.9 mg kg^{-1}) compared to soil application (23.2 mg kg^{-1}) at Syferkuil. It also resulted in increased crude protein, total N, P, Fe and Zn uptake compared to soil application at Ukulima. Both soil and foliar zinc application gave 28.5% zinc concentration in the fresh immature pods samples collected. Findings from this study reveal that foliar zinc sulphate application resulted in higher grain and biomass yields as well as zinc concentration in the various cowpea plant parts. Based on the quadratic model used in this study, the optimum zinc rate required to guarantee high cowpea yield and zinc-rich grain and leaf content at both trial sites is highly variable; and thus requires further study for validation.

Keywords: Cowpea production, grain yield, dryland farming, leafy vegetables, foliar fertilizer, improved nutrition, zinc deficiency.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATE

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background information to the study

Cowpea (*Vigna unguiculata* L.Walp) also known as black-eye pea, southern pea or crowder pea is a summer annual legume that originated from West Africa (Singh, 2003). It is widely grown in Africa, Latin America, South-East Asia and in the Southern parts of the United States of America. In South Africa, cowpea is locally known as *dinawa* and mostly grown by smallholder farmers (SHF) for its leaves as *morogo/imifino* under dryland farming conditions (DAFF, 2011). Nonetheless, few cases of commercial production are often observed for animal fodder; with only recent increased interest in grain production necessitated by the challenges around most rural household food insecurity (DAFF, 2011).

Cowpea plays a critical role in the lives of millions of rural people in many parts of Africa where it serves as a major source of dietary-protein in the predominantly cereal and starch-based food diet. It also serves as valuable and dependable commodity that generates income for producers and traders (Gómez, 2004). Nutritionally, cowpea grains contain 23-25% protein, 50-67% starch, and several vitamins and minerals (Keller, 2004; Sebetha *et al*., 2010) while immature green cowpea pods are reported to contain 17-25% protein and abundant essential minerals (Sebetha *et al*., 2010; Adeyemi *et al*., 2012). Green cowpea pods are often harvested and consumed as fresh vegetables over a period of several weeks during and after the “hungry period” (Cisse *et al.*, 1997). Hence, the crop has been described as a "hungry-season crop" given that it is the first crop to be harvested before the cereal crops are ready in Africa and is also cultivated in some parts of America and Asia (Gómez, 2004).

Zinc is an important micronutrient that is essential for growth and reproduction in plants, animals and humans. In plants, it plays a key role in the growth and development, DNA stabilization, gene expression, enzyme activity, protein synthesis and improved chlorophyll function (Prasad, 2003; Frassinetti *et al.,* 2006). Similarly, it is reported to play useful role in physical growth and development, the proper functioning of immune systems, reproductive health, sensory function and neuro-behavioural development in human (Holtz and Brown, 2004; Hirschfinkel *et al*., 2007).

Zinc deficiency has been described as one of the major widespread micronutrients disorder that contributes to public health problems in developing countries (WHO, 2002). Its deficiency represents a nutritional problem in many plants (Cakmak *et al*., 1999; Cakmak, 2002) and across a huge spectrum of people living on unbalanced diets dominated by a single staple grain such as rice (Virk and Barry, 2009). Such deficiency is reported to affect over 3 billion people worldwide (WHO, 2002; FAO, 2004; Long *et al*., 2004; Müller and Krawinkel, 2005) hampering growth and development; and destroying immune systems. Hotz and Brown (2004) reported that more than 19.7% of South Africa's population are at risk as a result of inadequate zinc intake. Thus, achieving increased zinc density in crops such as vegetables and grains has been recommended as an agriculturally-based intervention strategy to deal with the challenge of zinc malnutrition in human and animal rather than the conventional expensive food supplementation through biofortification (Bouis, 2003; Singh *et al*., 2009). This investigation was therefore initiated to find possible solution that may contribute towards achieving this strategy.

1.2 Problem statement

The problem of poor nutrition and micronutrient deficiency, particularly zinc, in the human diet among the rural poor in many parts of Sub-saharan Africa is a major public health concern (Weinberger and Swai, 2006). The situation is exacerbated by the high prices of micronutrients-rich foods and exotic leafy vegetables locally available in food stores, thereby leading to malnutrition and poor living condition among the rural poor. Also, the widespread low concentration of essential micro-nutrient such as zinc on agricultural farmlands in many parts of South Africa (Graham *et al*., 2001) constitutes a major limiting factor in the production of zinc-rich food and vegetable crops. Earlier reports by Barnard and Du Preez (2004) and Mandiringana *et al*. (2005) have suggested that both elemental and extractable zinc rates in South African cultivated farmlands including maize fields remain high. However, a recent survey of the extractable nutrient level in 168 surface soil samples from smallholder farms in Limpopo and North West provinces revealed a scary 78.6% zinc deficiency (Kutu, 2008). Obvious cases of zinc deficiency have similarly been reported elsewhere in the world, particularly in high pH soils under cereals (Ruel and Bouis, 1998). This is, therefore, a major source of concern for food and nutrition security in homes, particularly in many resource-poor communities where poverty and diseases are widespread.

1.3 Motivation for this study

South Africa is a developing country that is largely dominated by rural communities. Food and vegetables production by resource-poor farmers who represent the larger component of the farming community is mainly through low-input agricultural systems. Hence, the over-reliance on the consumption of uncultivated wild indigenous vegetables by millions of rural poor people due to their resource-poor state and low crop yield. Unfortunately too, the production requirement of the readily available exotic vegetables and other high-yielding field crops are beyond what the smallholder farmers can afford. Furthermore, the availability of these wild indigenous vegetables is being threatened by potential near future extinction due to over-exploitation arising increasing human and animal population pressure. This is further worsened by the current threat of climate change and global warming. Cowpea as a nutrient-rich grain and vegetable crop (Asiwe, 2009; Bansal *et al*., 1990; Bubenheim *et al*., 1990; Sebetha *et al*., 2010) has a great potential to fill this gap provided availability is guaranteed. Increase and sustainable production of cowpea as a vegetable crop through better production strategy will assist greatly in providing the required nutrient-rich foods by millions of South Africa's rural poor people. This will ensure access to cheaper and affordable vegetables and hence ensure better nutrition, prevent diseases and promote healthy life among rural communities.

1.4 Purpose of the study

1.4.1 Aim

This study is a component of a bigger cowpea agronomy project which is aimed at providing recommendation on appropriate zinc fertilization strategy that is suitable for the production of nutrients-rich cowpea.

1.4.2 Objectives

The objectives of this study were to:

i. assess the effect of zinc fertilizer application rates on the growth and yield components of cowpea.

ii. determine the effect of zinc fertilizer application rates on the chemical and nutritional components of cowpea.

iii. estimate the optimum zinc fertilizer rates for cowpea production under rainfed and irrigated field conditions.

iv. evaluate the interactive effect of zinc fertilizer rates and methods of application on the growth, yield and nutritional quality of cowpea.

1.5 Hypotheses

i. Zinc fertilizer application has no effect on the growth and yield components of cowpea.

ii. Zinc fertilizer application has no effect on the chemical and nutritional components of cowpea.

iii. The optimum zinc fertilizer rate for cowpea production under rain-fed and irrigated field conditions are different.

iv. There is no interaction between zinc fertilizer rates and methods of zinc application on the growth, yield and nutritional quality of cowpea.

CHAPTER 2

LITERATURE REVIEW

2.1 Botany of cowpea plant, its growth and adaptation

Cowpea is an annual herbaceous legume that can reach more than 80cm in height. Some varieties grow upright (indeterminate), while others have procumbent stems, often tinged with purple that trail along the ground (determinate). The large dark green trifoliate leaves provide a good ground cover that helps conserve soil moisture. Cowpea plant has a deep taproot with numerous spreading lateral roots that help stabilise the soil (Singh *et al.*, 1997). The flowers occur in alternate pairs and range in colour from dull white to yellow or lavender. They open in the early morning and close by about midday. Depending on the specific cultivar, the pods can be curved, straight or even coiled, while the seeds may vary in colour ranging from red, black, brown, tan or white; and may be speckled, spotted, or marbled. They also vary in shape from kidney-shaped to round depending on how they are tightly packed in the pod (Singh *et al.,* 1997).

Cowpea plant is drought tolerant, an attribute that makes it valuable in rainfed agriculture. As a legume, it replenishes low fertility soils when the roots are left to decay. It is widely grown mainly by small-scale farmers and often cultivated with other crops since it tolerates shade and is well-adapted to drier regions (Singh, 2003). Used as a cover crop, cowpea also suppresses weed, controls erosion and can encourage populations of beneficial insects to defend cash crops from insect pests (Agte *et al*., 2000; Singh, 2003). It has the useful ability to fix atmospheric nitrogen through its root nodules, and it grows well in poor soils with more than 85% sand, less than 0.2% organic matter and low rates of phosphorus (Booth *et al*., 1992).

2.2 Cowpea production and consumption in South Africa

South Africa is a country of national food self-sufficiency. However, hunger and malnutrition are still found in many rural and urban areas. Many people in this country still use a wide variety of plants in their daily lives for food, water, fuel, medicine and other necessities of life. These plants include vegetables whose fruits, seeds, roots, tubers, bulbs, stems, leaves, or flower parts are used as food. These vegetables account for 10% of the world's higher plants and consist of both indigenous and non-native plants (Mnzava, 1997). However, the indigenous vegetables are currently being under-utilised with a shift in favour of massive consumption of imported non-native vegetables and sometimes, refined and processed foods (Mnzava, 1997; Weinberger and Swai, 2006).

Cowpea is one of the under-utilized indigenous crops in South Africa despite its numerous advantages and the consumption by many resource-poor rural people. As a food for humans, cowpea can be consumed as green bean, protein-rich seed, as a coffee substitute (Agte *et al*., 2000; Asiwe, 2009) or prepared and taken as soup. Harvested fresh leaves of cowpea are often consumed by many South Africa rural people either solely as *morogo* or in combination with stiff porridge made from maize, sorghum, pearl millet, cassava or even boiled potato as relish with enhanced taste using tomato, onion and pepper. Parboiling of cowpea leaves like other vegetables before drying them is a widespread preservation method among the rural women while dried cowpea leaves are also sometimes ground into a powder, and stored for use in the dry season when fresh leaves are not available (Fennema, 1982). Cowpea leaves, dried or fresh, are commonly sold in local and urban markets whenever available (Grivetti and Ogle, 2000). In the livestock industry, cowpea fodder can be used for grazing, or baled for hay or silage.

2.3 Importance of indigenous vegetables and cowpea as nutrient-rich food sources

Vegetables are regarded to be of great importance in addressing the problem of nutrient imbalances since they contribute significantly to the amount of calories and nutrients in diets (Van den Heever *et al*., 2003; Akula *et al*., 2007; Faber *et al*., 2010). Indigenous (leafy) vegetable crops like cowpea have also been reported to provide valuable sources of nutrition in areas with hot, dry climates, particularly in the rural areas (Johns and Sthapit, 2004; Sebetha *et al*., 2010; Adeyemi *et al*., 2012). However, recent literature information revealed that the availability and use of indigenous (wild) vegetables has declined drastically possibly due to the long distance to be walked and/or workload for their collection and preparation, habitat change and excessive cultivation of field crops (Termote *et al*., 2012). This decline, particularly in many rural communities, has resulted in poor diets and increased incidence of nutritional deficiency disorders and diseases in many parts of Africa (Chadha and Oluoch, 2003). Concerns about the growing ignorance among young people about the existence of these nutritionally rich food plants have also been documented (Olorode, 2004). The scarcity of vegetables and nutrient-rich diets is therefore a major cause of vitamin A and micronutrient deficiency, which cause blindness and even death in young children throughout the semi-arid and arid areas of Africa (Martorell *et al*., 1990). Hence, the clarion calls for the prioritization of the conservation of various indigenous vegetable species (Freiberger *et al*., 1998).

2.4 The role of micronutrients in human diet

Approximately 40 vitamins and minerals are considered essential for physical and mental development, immune system and metabolic processes (Steyn *et al*., 2001). Zinc is an important trace element in human nutrition necessary to fulfil many biochemical functions during metabolism. It is the activation factor of several enzymes, including alkaline phosphatase and of several enzymes of the nucleic acid synthesis; stabilizes the structure of RNA, DNA and the ribosomes, and also influences hormone metabolism (Prasad, 2003). It is an essential element for plants that act as a metal component of various enzymes or as a functional structure or regulatory cofactor for protein synthesis, photosynthesis, the synthesis of auxin, cell division, and sexual fertilization (Hemn, 2013). Zinc deficiency in humans occurs in cases of inadequate zinc absorption or increased losses from the body through numerous biochemical pathways. Such deficiency also leads to several disorders such as growth retardation, diarrhoea, and interferences of cerebral functions (Institute of Medicine, 2001; Müller and Krawinkel, 2005).

Deficiency of iron, iodine and vitamin A in humans and animals have been described as the most widespread forms of micronutrients affliction while the prevalence of zinc and foliate deficiencies is thought to be significant (Steyn *et al*., 2001; Singh *et al*., 2009). Among the various micronutrients, Zn deficiency in both crops and humans ranged from 4 to 73% in different countries; and affect nearly one-third of world’s population (Maralian, 2009; Hotz and Brown, 2004). Micronutrients deficiency in plants can lead to severe depression in growth, yield, and crop quality (Njinga *et al*., 2013). Some soils do not contain sufficient amounts of these nutrients to meet the plant’s requirement for rapid growth and production. The supply of these micronutrients for rapid growth and yield in the form of foliar sprays is crucial with adequate knowledge of the elemental concentrations. Plants absorb the essential elements through their root systems or their leaves in various forms. Soil contains large amounts of all the elements, but only a very small percentage of these total amounts are actually useful for plant growth (Njinga *et al*., 2013). Micronutrient malnutrition is now a massive and rapidly growing public health problem among nearly all poor women, infants and children in many developing nations resulting in affecting about 40% of the world's population (Ramalingaswami, 1995). Zinc deficiency among women, infants and children may be as widespread globally as iron (Fe) deficiency because the dietary sources of the most bioavailable Fe are also the most important sources of bioavailable Zn in peoples' diets (Gibson, 1994). A diet which results in Fe deficiency, therefore, is likely to also predispose an individual to Zn deficiency. In many countries when Zn supplements are given to unfortunate children, growth rates increase demonstrating that Zn deficiency may be widespread (Gibson, 1994). Recent studies in some developing countries have reported that Zn supplements can reduce the severity and frequency of diarrhea in infants and children (Hambidge, 1992; Sazawal *et al*., 1996). Correction of such deficiency requires supplementary micronutrient application in the form of commercial fertilizers or foliar sprays (Prasad, 2003).

2.5 Addressing nutritional disorder through vegetable consumption

The consumption of vegetables constitutes an essential component of traditional human diets, particularly the wild vegetables among the rural populace. In a study in conducted in Limpopo province, Dovie *et al*. (2007) reported that 91% of households in rural communities harvested and consumed wild edible herbs, with a mean daily consumption of 0.2 kg per household. Thus, vegetable consumption has been promoted as the most practical and sustainable way to achieve improved nutrition since they constitute efficient and cheaper sources of several important micronutrients, both with respect to unit cost of production and per unit area of land (FAO, 2004). Indeed, there is a general consensus that wild foods could significantly contribute to alleviating hunger and malnutrition (Nesamvuni *et al*., 2001; Flyman and Afolayan, 2006). Hence, previously neglected crops such as cowpea including the non-commercial foods, have recently continued to receive renewed attention (Flyman and Afolayan, 2007a). This is due to the recognition that these neglected crops could become useful vehicle for improved nutrition, serve as convenient sources of income, increased food supply and household food security (Turan *et al*., 2003; Flyman and Afolayan, 2006; Faber *et al*., 2010).

There is increasing evidence to suggest that nutritional success is linked to diversification of the food base, which could be achieved by modifying agricultural practices and increasing the collection of wild plant germplasm (Singh, 2003). The fact that traditional rural communities are nutritionally successful, even during the periods of drought, affirms the importance of recognizing and utilizing traditional wild food resources. Hence, many authors have advocated the use of wild vegetables for combating micronutrient deficiencies in human diets (Walingo, 2005; Flyman and Afolayan, 2006; Flyman and Afolayan, 2007b).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Description of trial sites

The field trial was conducted at two locations during 2012-summer growing season in Limpopo Province, South Africa. These are Ukulima farm (24°54'94.72''S; 28°10'58.61''E, and 1237 m above sea level) near Modimolle under supplementary irrigation and at the University of Limpopo experimental farm, Syferkuil (23°50'36.86''S; 29°40'54.99''E; 1324 m above sea level) under rainfed condition. The trial at Ukulima farm was conducted on a Clovelly sandy soil with an average summer temperature range of 19.7°C to 28.6°C and average rainfall of 520 mm to 650 mm per annum. The trial at Syferkuil farm was conducted on a sandy loam Hutton soil where average rainfall ranged from 400 mm to 600 mm per annum with average summer day temperature range of between 18°C and 35°C, which could drop as low as 10+1°C during winter (Moshia *et al*., 2008).

3.2 Research design, treatments and trial layout

The experiment at each site was laid out in a split plot arrangement and fitted into a randomized complete block design (RCBD). Treatments consisted of zinc sulphate fertiliser application methods (soil and foliar) and zinc rates (0, 5, 10, 15, 20 and 25 kg ha^{-1}) with the main plots allocated to the application method and sub-plots assigned to the zinc rates. White cowpea variety (IT00K-1217) was sown as the test crop using hand manual planter at the depth of 10 cm. The variety is a dual purpose creeping determinate type and represents one of the two newly registered varieties in the country. Each trial consisted of 48 sub-plots that individually measured 3.75 m × 5 m (18.75 m^2) at Ukulima and 2.25 m × 5 m (11.25 m^2) at Syferkuil. The reduced sub-plot size at Syferkuil was due to restriction in land size. Seeds were sown at 20 cm intra row spacing and 75 cm inter row spacing on each plot and each treatment replicated four times. Ukulima planting was done on the 18th December 2012 while the Syferkuil trial was planted on the 11th January 2013. The delay in planting operation at Syferkuil was attributed to the delay in land preparation due to the breakdown of the tractor facility at the experimental farm. However, the potential confounding effect of variation in planting date in the trial across sites was avoided by ensuring that the trials received fairly the same agronomic or management practices throughout the planting season. Basal phosphorus (P) rate of 30 kg ha^{-1} was applied as single super phosphate (10.5% P) so as to eliminate P constraint. Pre-planting analysis of surface (0-15 cm) soil samples from the trial sites revealed Bray P1 content of 13.0 and 15.8 mg kg^{-1} and 0.1N HCl extractable zinc content of 2.16 and 4.36 mg kg^{-1}, respectively at Syferkuil and Ukulima. The clay percent content at Syferkuil (16%) and Ukulima (6.7%) also differed markedly. For soil application, zinc fertilizer was band placed at about 7 cm away from the row of cowpea plants after a thorough mix with 2-3 kg dried soil so as to achieve uniform application. Foliar application was achieved by dissolving measured quantity of the zinc sulphate salt based on the application rate in 2 L distilled water and sprayed on plant leaves. The zinc fertiliser application was done at 3-5 weeks after plant emergence when the plant roots had established themselves in the soil. Representative pre-planting surface soil (0-15 cm) sample was obtained from both sites after land preparation for laboratory determination using standard procedures.

3.3 Agronomic practices

Weeding was done regularly by hand hoeing at both trial sites. Incidences of insect infestation (Aphids) at both trial sites were regularly controlled as required using Karate 2.5 E.C at application rate of 75 ml ha^{-1} based on manufacturer's recommendation. Moisture stress condition in cowpea at Ukulima was regularly established based on visual monitoring (loss or turgidity and curling of leaves) to determine irrigation need. During each irrigation event, about 25 mm of irrigation water was often provided so as to prevent over-flooding.

3.4 Data collection

The following growth parameters were collected at six weeks after plant emergence (WAE) namely plant vigour as measured by the height of plants using a measuring tape, the number of primary branches and number of trifoliate leaves by counting on four randomly selected and tagged cowpea plants. Canopy cover which is the percentage of a fixed area covered by the crown of an individual plant was measured using a measuring tape on two middle adjacent plant rows at days to 50% flowering as well as at days to 50% pod formation.

Twenty young cowpea leaves and immature green pods were each harvested at approximately 75% physiological maturity for nutrient assessment. Data on day to 50% flowering and pod formation were also taken and recorded. Ten cowpea plants were harvested prior to physiological maturity between the two middle rows to estimate the biomass to determine the fodder weight.

Yield and yield component parameters were also obtained from the trials. Twenty fully developed fresh, immature pods were randomly harvested from the two middle rows of each plot at 10 weeks after plant emergence, weighed, oven-dried at 65^{o}C and used for nutrient analysis. The number of pods per plant, grain yield and fodder weight of dried cowpea plants from each plot were obtained at each harvest, while the shelling percentage a well as harvest index were thereafter calculated. The shelling percentage was calculated by dividing the total seeds/grains weight by the total pod weight, whereas harvest index was calculated by dividing the total seed or grain weight with the total above ground biomass as shown below:

$$\text{Harvest index} = \frac{\text{Economic Yield (seed yield/plant) X 100}}{\text{Biological yield (shoot dry weight)}}$$

The total above ground biomass was obtained through the sum of the recorded haulm, grain and fodder weights obtained at each harvest. Nutrients and nutritional quality determinations in leaf, pod and grain samples were carried out using standard laboratory procedures described by the Association of Analytical Chemists, AOAC, (1998). The nutrient analyses carried out included total nitrogen (N), phosphorus (P), zinc (Zn), and iron (Fe) contents while the percent crude protein (CP) content was estimated using the equation:

CP = TN x 6.25 (Jones *et al*., 1942; Greenfield and Southgate, 2003)

3.5 Data analysis

Growth and yield data as well as nutrient and nutritional quality parameters of the different plant parts were subjected to analyses of variance using Statistix 8.1 software. The treatments mean were separated using the Tukey's test at 5% level of significance. Data from the two locations were also tested for comparable magnitude through a weighted combined ANOVA so as to further eliminate any further confounding effects of variation in planting dates. The responses of the total above ground biomass, grain yield and pod fresh weight to the various zinc rates were modelled using the quadratic polynomial equation ($Y= a+b_1X+b_2X^2$) where: Y represents the total above ground biomass, grain yield or pod fresh weight; a is the intercept; b is the coefficient of the quadratic equation, X refers the zinc rate, which is optimised using the equation $X = -b_1/2b_2$ as cited by Alabi *et al*. (2013). The quadratic model was fitted to the experimental data manually by means of Excel Spread Sheet. The quadratic model was used because it gave the best fit.

CHAPTER 4

RESULTS

Treatment effects on growth parameters, yield and yield attributes

4.1 Growth parameters

4.1.1 Mean number of primary branches and trifoliate leaves per plant

Results obtained revealed that both the mean number of branches and trifoliate leaves per plant were significantly ($P \leq 0.05$) affected by the methods and rates of zinc application only at Ukulima (Table 1). Incremental rates of zinc application resulted in a significant reduction in both the mean number of trifoliate leaves as well as the mean number of branches per plant relative to the control treatment under supplementary irrigation at Ukulima but exerted no significant effects under dry land rainfed condition at Syferkuil. While there was no consistent pattern of reduction following increased zinc level under supplementary irrigation, there was a marginal increase only at 5 kg ha^{-1} application under rainfed. There was also no significant effect on zinc level x method of application interaction effects on both parameters.

4.1.2 Canopy cover, the number of days to 50% flowering, and pod formation

The result of treatment effects on canopy cover prior to flowering, the number of day to 50% flowering and day to 50% pod formation under supplementary irrigation at Ukulima are contained in Table 2. The results revealed that though there was no significant difference in canopy cover among the various treatments prior to flowering, the coefficient of variation between soil and foliar application was very high (23.5%). However at 50% flowering and pod formation, both the methods and rates of zinc application exerted significant ($P=0.05$) effects on canopy cover. The canopy cover was lower as the cowpea plants grow and mature through the various growth stages; but was much lowering soil than foliar application. The value of canopy cover measured at day to 50% flowering and pod formation increased following increase in the level of zinc application only up to 15 kg ha^{-1} beyond which, there was a decline.

Table 1: Treatment effect on the mean number of primary branches and trifoliate leaves per plant at 10 WAP

Treatments	**Ukulima**		**Syferkuil**	
	Number of primary branches	Number of trifoliate leaves	Number of primary branches	Number of trifoliate leaves
Methods of application (MA)				
Soil	5.4[a]	29.3[a]	5.9	44.1
Foliar	3.0[b]	16.4[b]	5.8	42.3
$P \leq 0.05$	*	**	ns	ns
CV%	30.3	15.1	7.2	12.5
Zinc rates, ZnL (kg ha^{-1})				
0	5.7[a]	31.3[a]	6.1	43.5
5	4.3[b]	24.6[ab]	6.3	46.2
10	3.7[b]	21.6[b]	5.8	41.6
15	3.7[b]	19.5[b]	5.6	40.4
20	4.0[b]	21.2[b]	5.8	43.8
25	3.7[b]	18.9[b]	5.6	43.6
$P \leq 0.05$	**	**	ns	ns
ZnL x MA interaction	ns	ns	ns	ns

ns= not significant; * implies significant at p = 0.05 while **implies significant at p= 0.001; CV= coefficient of variation

The method of zinc application exerted a significant (P=0.05) effect on both the mean number of days to 50% flowering and pod formation while the different zinc rates exerted a significant effect only on the mean number of days to 50% pod formation. Foliar application resulted in a significant delay in days to 50% flowering and hence resulted in a longer duration of 69 days as compared to 60 days for soil application without damage caused by the burning of cowpea leaves following foliar application of higher zinc at Ukulima under supplementary irrigation condition. Higher rates of zinc sulphate application from 15 kg ha^{-1} and beyond resulted in extended delay of the number of days to 50% flowering compared to the lower rates and the control. The number of days to 50% flowering ranged from 60 to 67 days while the number of days to 50% pod formation varied between 64 to 70 days depending on the method and level of zinc fertiliser application (Table 2).

4.1.3 Percentage plant damaged following foliar zinc fertiliser application

Foliar zinc application at higher rates resulted in a scorching effect and significant leaf damaging (Plate 1) on cowpea leaves under supplementary irrigation. Higher rates of zinc application resulted in a significant increase in the percentage plant damage relative to the control treatment (Figure 1). Higher application rates resulted in greater percent with up to 51.3% damage associated with 25 kg ha^{-1} zinc sulphate rate. This situation was however eliminated under rainfed dryland condition through delayed spraying of zinc sulphate to allow for better plant maturity. Burning effects of cowpea leaves was observed following foliar application of zinc fertiliser at 25 kg ha^{-1}, which resulted in a substantial growth and yield reduction at Ukulima (Plate 1).

Table 2: Treatment effect on phenological growth attributes under supplementary irrigation at Ukulima

Treatments	Canopy cover prior to flowering (cm)	Canopy cover at 50% flowering (cm)	Canopy cover at 50% pod formation (cm)	Days to 50% pod formation	Days at 50% flowering
Methods of application (MA)					
Soil	35.8	7.9^{b}	2.5^{b}	64.1^{b}	60.2^{b}
Foliar	39.4	27.8^{a}	12.9^{a}	71.5^{a}	68.9^{a}
P$\leq$0.05	ns	*	*	*	*
CV%	23.5	59.9	67.5	6.7	7.3
Zinc rates, ZnL (kg ha^{-1})					
0	36.0	8.5^{b}	2.9^{b}	64.5	60.9^{a}
5	32.4	9.3^{b}	3.0^{b}	65.4	63.6^{ab}
10	36.8	15.5^{ab}	6.6^{ab}	69.1	62.6^{ab}
15	45.4	30.8^{a}	15.1^{a}	69.5	67.4^{b}
20	39.4	24.6^{ab}	10.0^{ab}	68.3	66.5^{ab}
25	35.6	18.3^{ab}	8.6^{ab}	70.1	66.4^{ab}
P$\leq$0.05	ns	*	*	ns	*
ZnL x MA interaction	ns	ns	ns	ns	ns

ns= not significant;* implies significant at p = 0.05 while**implies significant at p= 0.001; CV= coefficient of variation; WAP implies weeks after planting

Plate 1: Scorching of cowpea leaves following foliar application of high zinc sulphate rates

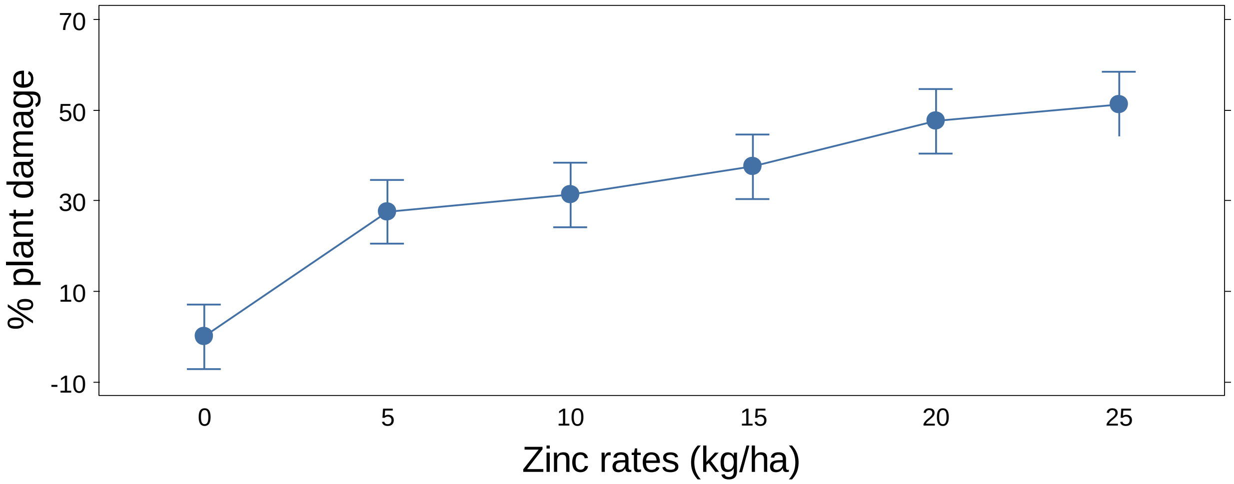

Figure 1: Percentage plant damage following incremental foliar zinc rates

4.2 Treatment effects on yield and yield attributes of cowpea

4.2.1 Fresh and dry pod weights

Table 3 showed that both the fresh and dry weights of the 20 immature pods harvested were significantly affected by the method and rates of zinc application only under supplementary irrigation. The mean fresh weight of 142.3 g obtained for 20 immature pods harvested where zinc fertilizer was soil applied under rainfed dryland condition was marginally higher than the 138.0 g obtained when foliar applied. Mean fresh weight of the of the 20 immature pods varied between 99.4 g and 161.7 g under supplementary irrigation condition but ranged from 138.8 g to 145.1 g under rainfed dryland condition depending on the zinc rate. A higher dry weight of 22.1 g for the of the 20 immature pods was obtained when zinc was soil applied compared to 14.5 g for foliar application under supplementary irrigation while the dry weight of 24.1 g and 23.6 g were obtained when zinc fertiliser was soil and foliar applied, respectively under rainfed dry land condition.

Incremental rates of zinc application resulted in a significant increase in the mean fresh pod weight but resulted in inconsistent reduction in the mean dry weight relative to the control treatment under supplementary irrigation. There was no significant zinc level x method of application interaction effects on both fresh and dry pod weights under both field conditions. Under dry land rainfed condition, neither the method nor rates of zinc application exerted any significant effects on both the mean fresh and dry pod weights. Nonetheless, the results of soil application were better than foliar application under both field conditions.

4.2.2 Fresh and dry biomass weights at 50% pods formation

The method of zinc application exerted a significant effect ($P<0.05$) on dry biomass and fresh biomass weight under supplementary irrigation and rainfed dry land condition, respectively (Table 3). Application of increased zinc rates resulted in higher but non-significant fresh and dry biomass weights under supplementary irrigation. The increase in fresh biomass weight following application of higher zinc level was truncated at 15 and 10 kg ha^{-1} under supplementary irrigation and rainfed dry land condition, respectively. Biomass production under soil application of zinc fertiliser gave better performance than foliar application. A significant zinc rate x method of application interaction effect ($P=0.05$) was only observed on fresh biomass weight under supplementary irrigation. Soil application gave a mean fresh biomass weight of 245.1 g/plant compared to 198.1 g/plant when zinc was foliar applied at 50% pod formation while mean fresh biomass weight ranged from 194.6 to 248.4 g/plant under supplementary irrigation condition.

Table 3: Treatment effect on selected growth attributes prior to plant full maturity under supplementary irrigation at Ukulima and rainfed dry land condition at Syferkuil

Treatments	Ukulima				Syferkuil			
	Fresh pod weight (g)	Dry pod weight (g)	Fresh biomass weight (g/plant)	Dry biomass weight (g/plant)	Fresh pod weight (g)	Dry pod weight (g)	Fresh biomass weight (g/plant)	Dry biomass weight (g/plant)
Method of application (MA)								
Soil	150.9[a]	22.1[a]	245.1	62.0[a]	142.3	24.1	152.5[a]	27.4
Foliar	124.0[b]	14.5[b]	198.1	47.0[b]	138.0	23.6	141.1[b]	24.9
$P \leq 0.05$	*	*	ns	*	ns	ns	*	ns
CV%	10.1	29.5	25.9	28.4	7.7	33.4	8.4	14.6
Zinc rates, ZnL (kg ha^{-1})								
0	99.4[b]	24.7[a]	217.5	53.8	138.8	22.1	136.5	25.2
5	142.1[a]	18.7[abc]	248.3	65.9	142.0	26.3	148.2	26.4
10	129.0[ab]	14.5[bc]	248.4	62.2	140.9	24.6	140.7	24.4
15	152.8[a]	12.6[c]	201.5	47.5	133.9	23.0	156.7	28.8
20	139.5[ab]	17.2[abc]	219.3	50.3	145.1	23.1	154.8	26.5
25	161.7[a]	22.1[ab]	194.6	47.3	140.2	24.1	144.1	25.8
$P \leq 0.05$	*	*	ns	ns	ns	ns	ns	ns
ZnL x MA interaction	ns	ns	**	ns	ns	ns	ns	ns

ns= not significant; *, **implies significant at p at 0.05 and 0.01, respectively; CV= coefficient of variation

Under dry land rainfed condition, soil and foliar application of zinc fertiliser gave cowpea fresh biomass weight of 152.5 g/plant and 141.1 g/plant, respectively at 50% pod formation while fresh biomass weight varied between 140.9 g/plant and 156.7 g/plant. On the other hand, dry biomass weight of 27.4 and 24.9 g/plant, respectively was obtained when zinc was soil and foliar applied under rainfed dry land condition but ranged from 24.4 to 28.8 g/plant depending on the zinc application level. Under supplementary irrigation, a significantly higher dry plant biomass weight with soil (62.0 g/plant) than foliar (47.0 g/plant) application were observed at 50% pod formation but ranged from 47.3 g/plant to 65.9 g/plant depending on the zinc application rate.

4.2.3 Plant population at harvest

Soil application of zinc fertiliser exerted marginal (2%) decrease in cowpea plant population compared to foliar application under supplementary irrigation (Table 4) but decreases it by 5% under dry land rainfed condition (Table 5). Generally, cowpea plant population decreased by between 3 and 10% across the different zinc rates following the different rates of zinc sulphate application under supplementary irrigation but declined by between 5 and 7% under dry land condition. A combined analysis of variance for plant population across the two trial sites showed a significant ($P \leq 0.001$). The results also revealed that plant population was affected by the method of application ($P \leq 0.05$) under rainfed condition.

4.2.4 Mean number of pods per plant at harvest

The mean number of pods per plant in each of the two methods of application as well as across the various zinc rates under supplementary irrigation differed significantly (Table 4). Soil application of zinc fertiliser resulted in significantly higher pod counts per plant than foliar application while incremental zinc level resulted in a lower pod counts per cowpea plant. There was no significant zinc level x method of application interaction effects on the mean number of pods per plant.

Table 4: Treatment effect on cowpea grain yield and yield attributes obtained at harvest under supplementary irrigation at Ukulima

Treatments	Plant population (ha^{-1})	Number of pods/ Plant	Grain yield ($kg\ ha^{-1}$)	Fodder weight ($kg\ ha^{-1}$)	Haulm weight ($kg\ ha^{-1}$)	Total above ground biomass ($kg\ ha^{-1}$)	Harvest index (%)	Shelling percentage
Method of application (MA)								
Soil	47044	22.7^{a}	2251^{a}	3169	878.5^{a}	6299^{a}	36	72.0^{b}
Foliar	48133	13.8^{b}	1503^{b}	2970	319.0^{b}	4792^{b}	31	85.1^{a}
$P \leq 0.05$	ns	*	*	ns	**	*	ns	**
CV%	25	19.7	15.6	33.6	16.51	12.76	22.48	25.1
Zinc rates, ZnL ($kg\ ha^{-1}$)								
0	49733	22.5^{a}	2200^{a}	2849	816.8^{a}	5866	38^{a}	73.1^{b}
5	48134	20.7^{ab}	2062^{ab}	3199	645.5^{ab}	5906	35^{ab}	77.2^{ab}
10	46667	20.1^{ab}	1884^{abc}	3143	589.0^{ab}	5616	34^{ab}	78.5^{ab}
15	44733	14.8^{ab}	1718^{bc}	3049	525.5^{b}	5292	32^{ab}	81.3^{a}
20	49467	18.0^{ab}	1793^{bc}	3052	531.8^{b}	5377	34^{ab}	80.0^{ab}
25	46800	13.6^{b}	1604^{c}	3127	484.0^{b}	5215	30^{b}	81.0^{a}
$P \leq 0.05$	ns	*	**	ns	*	ns	*	*
ZnL x MA interaction	ns	ns	*	*	*	*	*	*

ns= not significant; *, **implies significant at p at 0.05 and 0.01, respectively; CV= coefficient of variation

Table 5: Treatment effect on cowpea grain yield and yield attributes obtained at harvest under dry land rainfed condition at Syferkuil

Treatments	Plant population (ha^{-1})	Grain yield (kg ha^{-1})	Fodder weight (kg ha^{-1})	Haulm weight (kg ha^{-1})	Total above ground biomass (kg ha^{-1})	Harvest index (%)	Shelling percentage
Method of application (MA)							
Soil	142296[b]	2771	2225	1223	6219	45.0	69.3
Foliar	149778[a]	2723	2094	1204	6020	45.6	69.4
$P \leq 0.05$	*	ns	ns	ns	ns	ns	ns
CV%	5.6	11.3	27.5	17.8	9.0	12.0	4.2
Zinc rates, ZnL (kg ha^{-1})							
0	145111	2786	2457	1221	6464	43.7	69.7
5	144445	2869	2337	1164	6370	45.4	71.2
10	143333	2726	2227	1271	6226	44.0	68.1
15	141334	2679	1942	1172	5793	46.5	69.5
20	151333	2713	1899	1218	5830	46.9	69.0
25	150667	2707	2094	1234	6035	45.1	68.6
$P \leq 0.05$	ns	ns	ns	ns	ns	ns	ns
ZnL x MA interaction	ns	ns	*	ns	ns	ns	ns

ns= not significant;* implies significant at p = 0.05; CV = coefficient of variation

4.2.5 Grain yield

Grain yield was significantly (P<0.05) higher when zinc was soil applied (2251 kg ha^{-1}) than when foliar applied (1503 kg ha^{-1}) under supplementary irrigation (Table 4). A similarly higher, though not significant, grain yield was obtained when zinc fertiliser was soil applied (2771 kg ha^{-1}) than foliar application (2723 kg ha^{-1}) under dry land condition (Table 5). Incremental level of zinc application resulted in a significant decline in grain yield under supplementary irrigation while the 5 kg Zn ha^{-1} rate gave higher grain yield increase relative to other application rates. The latter is also true under dry land condition.

4.2.6 Fodder weight

Total fodder weight across the two methods of zinc application and various zinc rates under both field conditions did not differ significantly (Table 4 & 5). Soil application of zinc fertiliser gave a total fodder weight of 3169 kg ha^{-1} while foliar application gave 2970 kg ha^{-1} under supplementary irrigation condition. Similarly, soil application gave a higher total fodder weight (2225 kg ha^{-1}) than foliar application (2094 kg ha^{-1}) under dry land condition. Total fodder weight ranged from 1899 to 2337 kg ha^{-1} under dry land condition compared to a range of 3049 to 3199 kg ha^{-1} under supplementary irrigation across the various zinc rates. There was a significant (P<0.05) application method x zinc fertiliser level interaction effects on the total fodder weight under both field conditions.

4.2.7 Haulm weight

Both the method of application and zinc rates exerted a significant ($P \leq 0.05$) effect on haulm weight only under supplementary irrigation condition (Table 4). Incremental level of zinc application showed significant increases in mean haulm weight relative to control treatment only at 10 and 25 kg ha^{-1} at Ukulima under supplementary irrigation. There was a significant zinc level x method of application interaction effects on haulm weight under supplementary weight (Table 4). Soil application of zinc fertiliser gave a higher total haulm weight than foliar application under both supplementary irrigation and dry land field conditions. Total fodder weight ranged from 484.0 to 816.8 kg ha^{-1} under supplementary irrigation but varied between 1164 to 1234 kg ha^{-1} under dry land rainfed conditions depending on the zinc rate.

4.2.8 Harvest index

The results obtained revealed incremental rates of zinc application resulted in a significant ($P<0.05$) reduction in HI relative to the control treatment under supplementary irrigation (Table 4) but resulted in a significant increase relative to the control treatment under dry land condition (Table 5). Soil application of zinc fertiliser gave a mean HI of 36% while foliar application gave 31% under supplementary irrigation while on the other hand, soil and foliar application gave mean HI of 55.0% and 45.6%, respectively under rainfed condition.

4.2.9 Shelling percentage

The method of zinc fertiliser application had a significant ($P\leq0.05$) effect on the shelling percentage under supplementary irrigation condition (Table 4) but exert inconsequential effects under rainfed condition (Table 5). Incremental level of zinc application resulted in a significant reduction in the mean shelling percentage under irrigation but gave a marginal increase only at 5 kg ha^{-1} application rate under rainfed. Soil application gave a mean shelling percentage value of 72.0% while foliar application gave 85.1% under supplementary irrigation compared to 69.4% and 69.3% that were obtained when foliar and soil applied, respectively under rainfed condition. The 15 kg ha^{-1} zinc application rate gave the highest mean shelling percentage of 81.3% while 5 kg ha^{-1} gave the highest value of 71.2%.

4.2.10 Total above ground biomass at harvest

The total above ground biomass of cowpea was significantly ($P\leq0.05$) affected by the application method of zinc sulphate. Soil application of Zn gave a biomass yield of 6298 kg ha^{-1} compared to 4791 kg ha^{-1} by foliar application under supplementary irrigation (Table 5). Mean above ground biomass yield ranged from 5215 kg ha^{-1} to 5906 kg ha^{-1} across the various zinc rates under supplementary irrigation but varied between 5793 kg ha^{-1} and 6464 kg ha^{-1} under dry land rainfed condition. The mean total above ground biomass yield of 6219 kg ha^{-1} following soil application of zinc sulphate was comparable to the 6019 kg ha^{-1} obtained when foliar applied under dry land rainfed condition.

4.3 Treatments interaction effect on growth parameters, yield and yield attributes

A significant zinc level x method of application interaction effects on grain yield, haulm weight, fodder weight, HI and total above ground biomass was observed under supplementary irrigation (Table 6) while the interaction was only significant ($P<0.001$) for fodder weight under dry land rainfed condition. Although zinc application gave a general grain yield reduction relative to the control treatment under supplementary irrigation, incremental zinc rate up to 15 kg ha^{-1} increased grain yield when soil applied. Grain yield declined generally following foliar zinc application and worsened at higher application rates. Decrease in fodder weight was similarly obtained following incremental zinc level when foliar applied but resulted in a general inconsistent increase when soil applied under supplementary irrigation. Haulm weight and the total above ground biomass under supplementary irrigation inconsistently decreased following incremental zinc level following foliar application compared to interaction of foliar application and zinc rates. Fodder weight and the total above ground biomass generally increased relative to the control with increase in zinc rate following soil application. The shelling percentage was generally improved following zinc fertilisation with the highest value obtained at 15 kg ha^{-1} (90.0%) under foliar and 25 kg ha^{-1} (73.2%) under soil application.

Overall, the performance of the measured variable was better under soil application than foliar considering the significant interaction between the two treatments factors i.e. method of application and zinc rates at Ukulima under supplementary irrigation condition. Similarly, a significant method of application x zinc rate interaction effect was obtained on fodder weight following incremental zinc level under rainfed dryland condition (Table 7). A general decline in fodder weight at higher zinc rates for both methods of application was observed except the 5 kg ha^{-1} rate that was marginally beneficial when soil applied.

Table 6: Application method x zinc level interaction effects on cowpea yield attributes under supplementary irrigation at Ukulima

Treatments		Grain yield ($kg\ ha^{-1}$)	Fodder weight ($kg\ ha^{-1}$)	Haulm weight ($kg\ ha^{-1}$)	Total above ground biomass ($kg\ ha^{-1}$)	Shelling percentage
Method of application	**Zinc rates ($kg\ ha^{-1}$)**					
Soil	0	4.4	2398	2.4	5657	71.9
Soil	5	4.1	3561	2.3	6617	72.4
Soil	10	4.2	3444	2.4	6548	72.3
Soil	15	4.3	3363	2.3	6587	71.0
Soil	20	4.1	3260	2.6	6352	71.0
Soil	25	4.2	2990	2.4	6031	73.2
Foliar	0	3.9	3301	2.2	6075	74.2
Foliar	5	3.6	2837	2.1	5195	82.0
Foliar	10	2.9	2842	1.7	4683	84.7
Foliar	15	2.2	2735	1.3	3998	92.0
Foliar	20	2.6	2844	1.6	4402	89.1
Foliar	25	1.9	3264	1.2	4399	88.8
F-value at P = 0.01		4.7	3.0	4.4	4.4	3.4

**implies significant at p= 0.01; CV= coefficient of variation

Table 7: Application method x zinc level interaction effects on cowpea fodder weight under dry land rainfed condition at Syferkuil

Treatments		Fodder weight (kg ha^{-1})
Method of application	**Zinc rates (kg ha^{-1})**	
Soil	0	2633
Soil	5	2666
Soil	10	2342
Soil	15	1726
Soil	20	1803
Soil	25	2179
Foliar	0	2282
Foliar	5	2008
Foliar	10	2113
Foliar	15	2157
Foliar	20	1994
Foliar	25	2009
F-value at P = 0.01		1.4

4.4 Quadratic polynomial regression for the measured parameters

Treatments had a highly significant effect on grain yield (P = 0.001) and fresh pod weight (P = 0.002) under supplementary irrigation only. Yield components under supplementary irrigation had a correlation of 0.70 to 0.94 (Figure 2, 3 and 4) but varied between 0.03 and 0.80 under rainfed condition (Figure 5, 6 and 7). Based on the quadratic models, total biomass 4897 kg ha^{-1} and grain 1602 kg ha^{-1} yields were optimised at an estimated zinc rate of 54.7 and 33.4 kg ha^{-1}, respectively under supplementary irrigation (Table 8). Total biomass 5913 kg ha^{-1} and grain 2696 kg ha^{-1} yields were obtained at an estimated optimum zinc rate of 20.1 and 26.8 kg ha^{-1}, respectively under rainfed condition (Table 7). Fresh pod weight of 155 g and 140 g $plot^{-1}$ per twenty pods was optimised at 25.2 kg ha^{-1} and 8.5 kg ha^{-1} zinc application rate under supplementary irrigation and rainfed condition, respectively (Table 8).

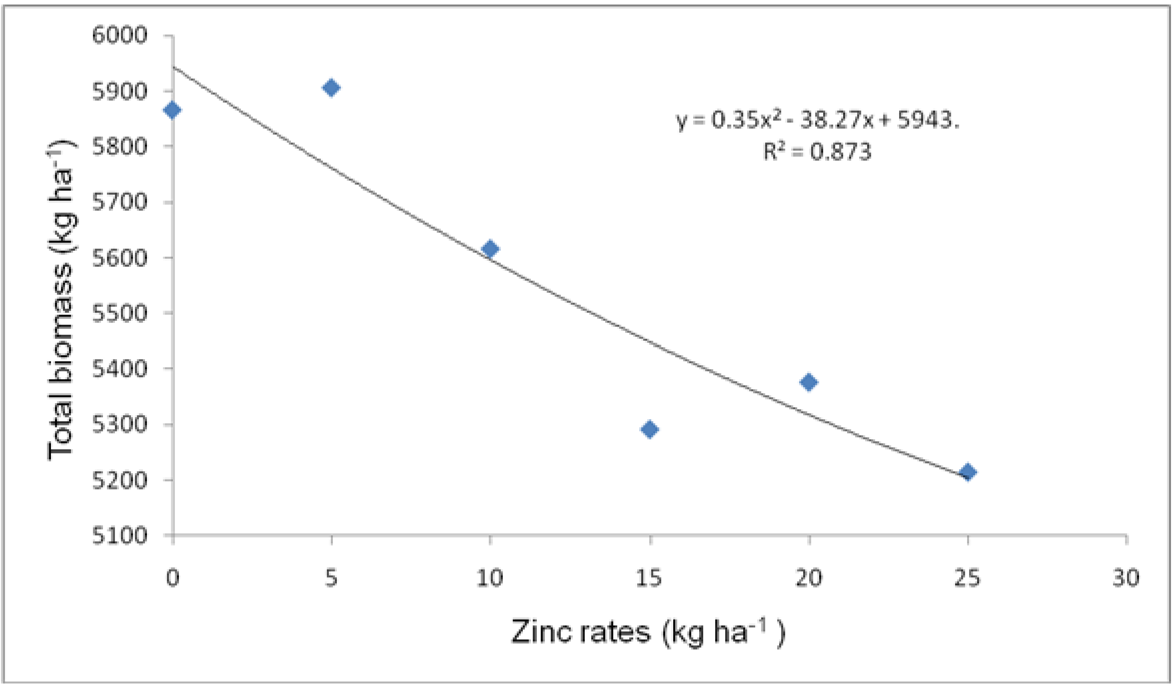

Figure 2: Quadratic polynomial of total biomass versus zinc rates at Ukulima farm

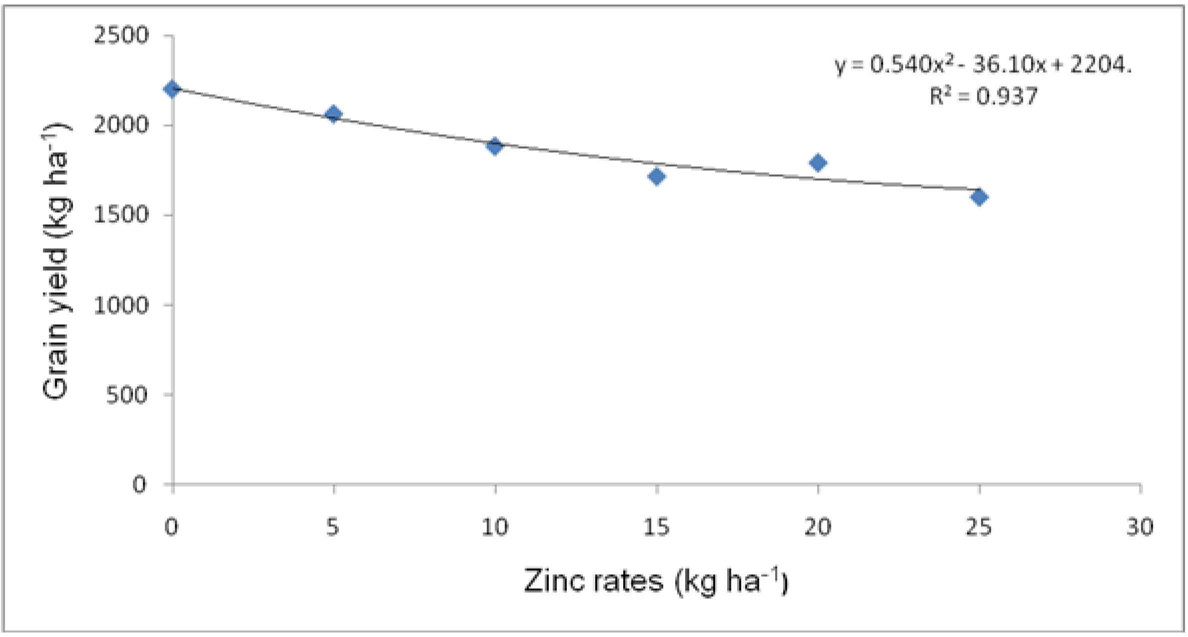

Figure 3: Quadratic polynomial of grain yield versus zinc rates at Ukulima farm

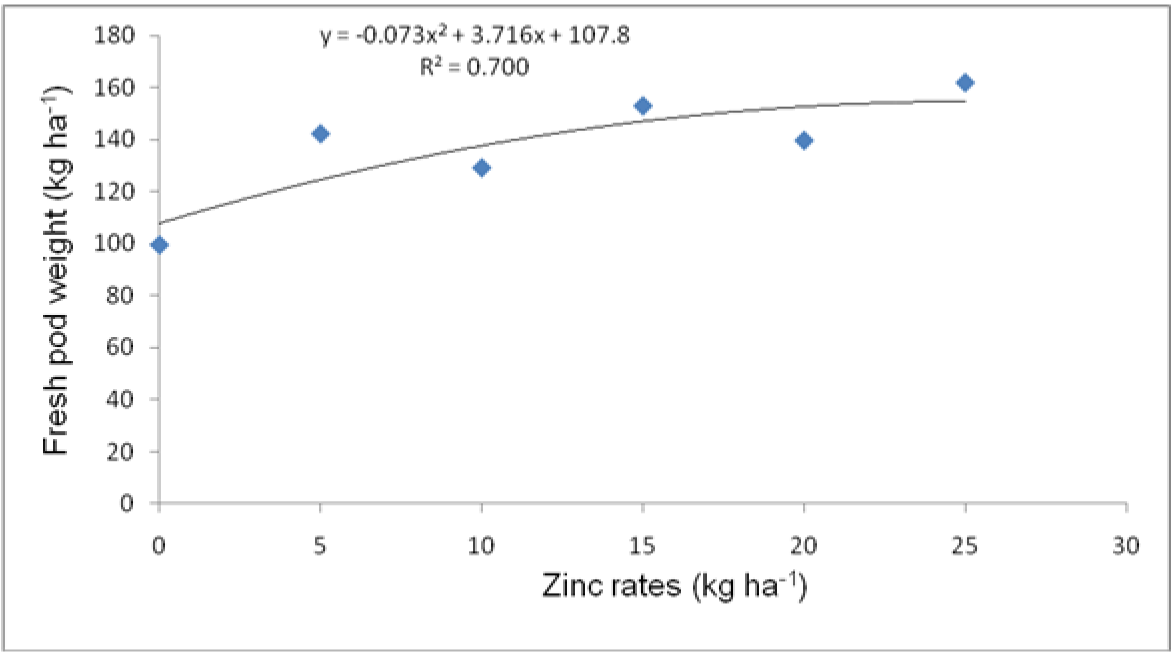

Figure 4: Quadratic polynomial of fresh pod weight versus zinc rates at Ukulima farm

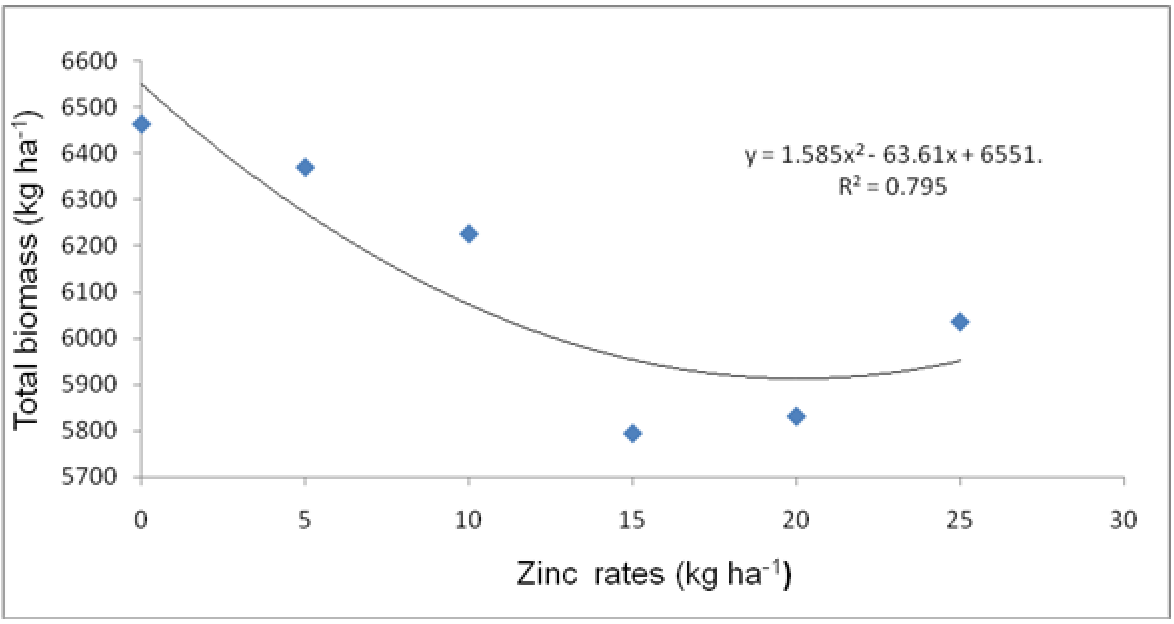

Figure 5: Quadratic polynomial of total biomass versus zinc rates at Syferkuil farm

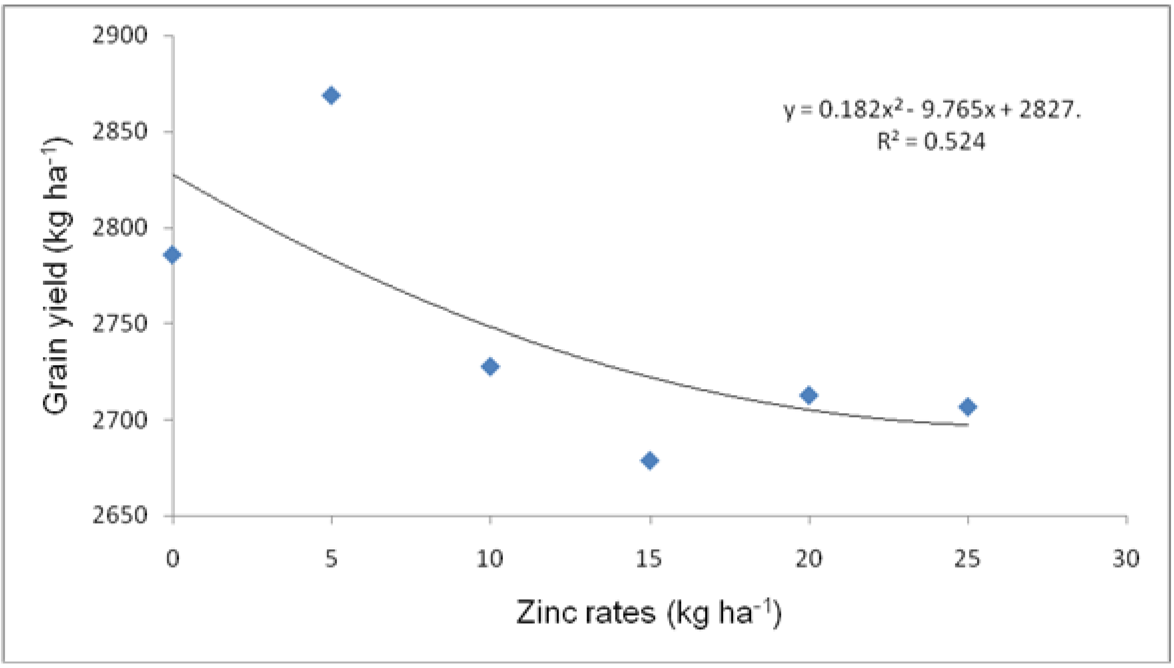

Figure 6: Quadratic polynomial of grain yield versus zinc rates at Syferkuil farm

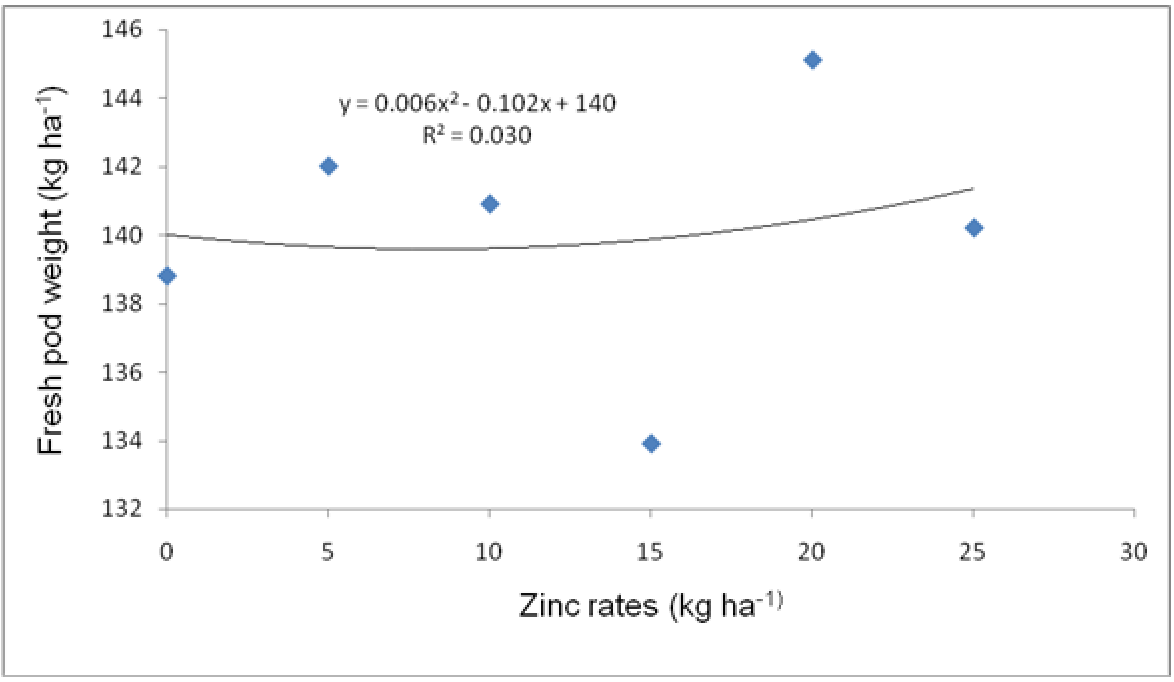

Figure 7: Quadratic polynomial of fresh pod weight versus zinc rates at Syferkuil farm

Table 8: Quadratic equation of the various response parameters with the zinc rates as independent variable and the corresponding R^2 values of the equation, Estimates of optimum zinc rate (X) and yield parameters (Y) based on the tested model

Field condition	Parameters	Regression equation	R^2value	P	X	Y-value
Supplementary irrigation condition	Total biomass	$Y = 5943 - 38.27X + 0.35X^2$	0.873	0.171	54.7	4897
	Grain yield	$Y = 2204 - 36.10X + 0.540X^2$	0.937	0.001	33.4	1602
	Fresh pod weight	$Y = 107.8 + 3.716X - 0.073X^2$	0.700	0.002	25.2	155
Dryland rainfed condition	Total biomass	$Y = 6551 - 63.61X + 1.585X^2$	0.795	0.315	20.1	5913
	Grain yield	$Y = 2827 - 9.765X + 0.182X^2$	0.524	0.832	26.8	2696
	Fresh pod weight	$Y = 140 - 0.102X + 0.006X^2$	0.030	0.558	8.5	140

P= significant value; R^2= measured response

4.5 Nutrient content and uptake in plant tissues as affected by different treatments

4.5.1 Leaf tissue analysis

The measured mean nutrients contents as well as nutrient uptake in harvested leaf samples across the different methods and rates of zinc application under dry land rainfed condition did not differ significantly except for zinc content and uptake, which were significantly ($P \leq 0.05$) higher when foliar applied (Table 9). Nonetheless, the mean percentage crude protein, total nitrogen, phosphorus and iron contents in the harvested leaves were quantitatively higher under foliar than soil application but decreased with incremental zinc rates. A non-significant difference in the mean content and uptake of all measured parameters was obtained in harvested cowpea leaf samples for the trial under supplementary irrigation condition (Table 10).

4.5.2 Analysis of immature green pods

The difference in the mean content and uptake of total nitrogen, phosphorus, iron, zinc, total nitrogen uptakes, phosphorus uptakes, Iron for the harvest immature green pods across the different treatments under dry land rainfed condition were not significant; but the coefficient of variation among the two methods of applications was quite high (Table 11). The mean crude protein, total nitrogen, and phosphorus contents as well as iron and zinc uptakes of harvested immature green pods from were significantly affected by method of application ($P \leq 0.05$) under supplementary irrigation condition (Table 12). The values for these parameters were generally higher in foliar treatments.

4.5.3 Grain analysis from Syferkuil and Ukulima trials

The results of grain nutrients analysis revealed a non-significant difference in the mean content of crude protein, total nitrogen, phosphorus, iron, zinc as well as uptake of these nutrients across both methods and rates of zinc application under dry land rainfed condition (Table 13). However, results under supplementary irrigation condition revealed a significant ($P \leq 0.05$) difference in seeds/grain tissue nitrogen and phosphorus uptakes; being significantly lower following foliar application (Table 14).

Table 9: Impact of treatments on selected nutrient content and uptake in harvested leaves samples under dry land rainfed conditions at Syferkuil

Treatments	Crude protein (%)	Nutrients content				Nutrients uptake (mg kg^{-1})			
		Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Method of application									
Soil	18.2	2.92	0.20	139	23.2 [b]	0.12	0.01	0.54	0.09[b]
Foliar	18.9	3.02	0.21	144	43.9[a]	0.11	0.01	0.54	0.16[a]
P≤0.05	ns	ns	ns	ns	**	ns	ns	ns	*
CV%	12.3	12.3	19.5	32.4	27.1	4.0	16.4	38.5	33.5
Zinc rates (kg ha^{-1})									
0	19.2	3.07	0.21	180	21.1	0.12	0.01	0.70	0.08
5	17.7	2.83	0.20	139	33.5	0.12	0.01	0.57	0.14
10	17.9	2.86	0.19	135	41.4	0.11	0.01	0.53	0.16
15	18.3	2.93	0.20	138	41.3	0.10	0.01	0.49	0.15
20	18.5	2.95	0.20	130	32.6	0.11	0.01	0.48	0.12
25	19.8	3.17	0.21	128	31.2	0.12	0.01	0.48	0.12
P≤0.05	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns= not significant; *, **implies significant at p at 0.05 and 0.01, respectively; CV= coefficient of variation

Table 10: Treatment effects on selected nutrient content in harvested leaves samples under supplementary irrigation condition at Ukulima

Treatments	Crude protein %	Total Nitrogen %	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})
Method of application					
Soil	28.9	5.91	0.24	261	27.2
Foliar	36.9	4.62	0.40	312	32.8
$P \leq 0.05$	ns	ns	ns	ns	ns
CV%	90.3	90.3	84.0	25.4	116.4
Zinc rates (kg ha^{-1})					
0	21.3	3.40	0.23	246	23.8
5	18.2	2.91	0.19	234	49.2
10	38.6	6.18	0.41	284	25.2
15	34.6	5.53	0.17	311	25.1
20	31.2	4.99	0.30	350	29.1
25	53.5	8.56	0.62	295	27.5
$P \leq 0.05$	ns	ns	ns	ns	ns

ns= not significant; CV= coefficient of variation

Table 11: Effect of methods and rates of zinc application on selected nutrient content and uptake as well as nutritional content in immature green pods at Syferkuil

Treatments	Nutrients content					Nutrient Uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Method of application									
Soil	21.1	3.38	0.31	45.9	33.0	0.84	0.08	1.10	0.80
Foliar	22.6	3.61	0.35	48.6	35.3	0.87	0.08	1.14	0.83
$P \leq 0.05$	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	119.9	119.9	34.3	59.1	9.4	153.9	27.6	54.9	38.4
Zinc rates (kg ha^{-1})									
0	16.2	2.60	0.32	49.6	33.1	0.56	0.07	1.02	0.73
5	16.9	2.70	0.34	45.7	34.1	0.71	0.09	1.23	0.90
10	18.2	2.91	0.37	56.2	34.0	0.72	0.09	1.40	0.84
15	32.3	5.17	0.32	35.9	32.4	1.28	0.07	0.81	0.75
20	32.1	5.13	0.32	48.8	35.5	1.29	0.07	1.14	0.82
25	15.3	2.45	0.31	47.4	35.5	0.60	0.07	1.12	0.85
$P \leq 0.05$	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns= not significant; CV= coefficient of variation

Table 12: Effect of method of application and zinc rates on selected nutrient content and uptake as well as nutritional content in immature green pods under supplementary irrigation condition at Ukulima

Treatments	Crude protein %	Nutrients content				Nutrient Uptake (mg kg^{-1})			
		Total Nitrogen %	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Nitrogen	Phosphorus	Iron	Zinc
Method of application									
Soil	20.4^{b}	3.23^{b}	0.40^{b}	110	24.1	0.62	0.08	2.55^{a}	0.56^{a}
Foliar	24.4^{a}	3.95^{a}	0.51^{a}	115	28.9	0.51	0.06	1.49^{b}	0.40^{b}
$P \leq 0.05$	*	*	*	ns	ns	ns	ns	*	*
CV%	16.0	16.0	16.6	50.9	23.7	35.2	36.7	46.2	30.4
Zinc rates (kg ha^{-1})									
0	19.7	3.14	0.37	86	24.6	0.81^{a}	0.08	1.92	0.54
5	21.8	3.48	0.43	110	26.0	0.65^{ab}	0.07	1.87	0.44
10	24.5	3.93	0.49	107	28.0	0.57^{ab}	0.04	0.82	0.23
15	24.7	3.95	0.52	114	29.3	0.44^{b}	0.06	1.62	0.34
20	22.0	3.51	0.43	94	27.9	0.60^{ab}	0.07	1.41	0.42
25	21.9	3.50	0.43	141	23.3	0.76^{ab}	0.09	2.89	0.52
$P \leq 0.05$	ns	ns	ns	ns	ns	*	ns	ns	ns

ns= not significant;* implies significant at p = 0.05; CV= coefficient of variation

Table 13: Effect of method of application and zinc rates on selected nutrient content and uptake in cowpea grains under dry land rainfed condition at Syferkuil

Treatments	Nutrients content					Nutrient Uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Method of application									
Soil	22.4	3.58	0.47	36.5	32.3	99	12.85	99	90
Foliar	21.6	3.45	0.44	29.1	34.1	94	12.10	79	93
$P \leq 0.05$	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	7.2	7.2	7.2	111.5	15.2	13.4	8.9	107.1	14.5
Zinc rates (kg ha^{-1})									
0	22.0	3.52	0.46	24.7	33.6	98	12.92	69	95
5	21.9	3.50	0.45	69.5	33.1	100	13.05	189	95
10	20.6	3.29	0.42	25.8	34.3	91	11.55	72	93
15	21.3	3.41	0.44	27.9	32.6	90	11.57	73	87
20	23.6	3.77	0.47	14.5	32.0	102	12.85	37	86
25	22.5	3.59	0.48	34.5	33.8	97	12.90	93	92
$P \leq 0.05$	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns= not significant; CV= coefficient of variation

Table 14: Effect of method of application and zinc rates on selected nutrient content and uptake in cowpea grains under supplementary irrigation condition at Ukulima

Treatments	Nutrient content					Nutrient uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Method of application									
Soil	19.4	3.10	0.39	76	48.9	69.6[a]	8.69[a]	167	111
Foliar	19.9	3.18	0.40	85	43.2	48.1[b]	6.08[b]	124	64
$P \leq 0.05$	ns	ns	ns	ns	ns	**	**	ns	ns
CV%	8.4	8.4	20.7	78.0	66.2	20.0	8.2	58.4	89.8
Zinc rates (kg ha^{-1})									
0	19.9	3.18	0.41	93.1	43.1	69.9 [a]	8.94[a]	193	94
5	19.1	3.05	0.40	74.4	43.0	62.7[ab]	8.29[ab]	155	89
10	20.5	3.28	0.40	69.0	41.5	61.8[ab]	7.58[ab]	130	79
15	19.3	3.09	0.37	96.6	39.5	52.4[ab]	6.41[ab]	142	69
20	20.1	3.21	0.41	65.7	39.6	56.7[ab]	7.18[ab]	122	71
25	19.0	3.03	0.36	81.3	69.5	49.5[b]	5.91[b]	131	124
$P \leq 0.05$	ns	ns	ns	ns	ns	*	*	ns	ns

ns= not significant; *, **implies significant at p at 0.05 and 0.01, respectively; CV= coefficient of variation

4.5.4 Nutritional and nutrient content of cowpea leaves as affected by variation in trial sites

The mean crude protein, total nitrogen and iron contents in the harvested cowpea leaves over the different treatments differed significant ($P \leq 0.05$) across the two trial sites; being generally higher at Ukulima (Table 15). Although the mean zinc content in leaf samples obtained from both sites did not significantly from each other, value obtained Syferkuil was 13.6% higher than that from Ukulima.

Table 15: Variation in the mean contents of crude protein and selected nutrients in harvested leaf samples over different treatment factors across the two trial sites

Trial sites	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})
Ukulima	32.2[a]	5.23[a]	0.34[a]	279[a]	29.6
Syferkuil	18.6[b]	2.97[b]	0.20[b]	142[b]	33.5
$P \leq 0.05$	**	**	*	**	ns

ns= not significant; *, **implies significant at probability of 0.05 and 0.01, respectively while connotes coefficient of variation

The mean phosphorus content, iron and zinc contents in immature green pods and dried grains as well as the crude protein and total nitrogen content in dried cowpea grain from the two trial sites differed significantly ($P<0.05$) (Table 16). The Crude protein, total nitrogen, phosphorus and iron contents were higher in pod samples from Ukulima while the reverse was the case with dried grain samples. The uptake of total N and iron were higher in Ukulima grain samples while phosphorus and zinc uptake were higher in Syferkuil dried harvested grain samples. The mean iron and zinc uptake across the various treatment for green pods obtained from the two trial sites also differed significantly ($P<0.001$) with value being higher at Ukulima and Syferkuil, respectively.

Table 16: Variation in the mean contents of crude protein and selected nutrient in harvested immature green pods and dried grain across the two sites

Treatments	Nutrient content					Nutrient uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Immature green pods									
Ukulima	22.1	3.54	0.44[a]	108[a]	26.5[b]	0.57	0.07	1.76[a]	0.41[b]
Syferkuil	21.8	3.49	0.33[b]	47[b]	34.1[a]	0.86	0.08	1.12[b]	0.81[a]
$P \leq 0.05$	ns	ns	**	**	**	ns	ns	**	**
Cowpea grains									
Ukulima	19.6[b]	3.14[b]	0.39[b]	80.0[a]	46.0[a]	96.7[a]	7.39[b]	145[a]	88
Syferkuil	22.0[a]	3.51[a]	0.45[a]	32.8[b]	33.2[b]	58.8[b]	12.48[a]	89[b]	91
$P \leq 0.05$	**	**	**	**	**	**	**	**	ns

ns= not significant;**implies significant at p= 0.01; CV= coefficient of variation

CHAPTER 5

DISCUSSIONS

5.1 Treatment effects on growth parameters

The results of this study clearly indicated differential responses of cowpea plant performance to the various treatments under the two field conditions. The observed significant depressive effects of foliar zinc fertiliser application exerted on plant vigour under supplementary irrigation contradict earlier findings by Sajid *et al*. (2010) who reported increased vigour, leaf size and shoot growth and recovery following foliar application on severely Zn-deficient citrus trees. The latter might be associated to better resistance to injury and faster recovery after burn possibly as a result of the timing of the foliar application (Maralian, 2009).

The increased, though not significantly, leaf fresh and dry weights under dry land rainfed condition for both soil and foliar application were comparable to earlier work by Thalooth *et al*. (2006) who reported that spraying mungbean plants with Zn and K resulted in taller, greater number and weight of leaves relative to the control. Such enhancement effect might be attributed to the complementary or synergistic effect of application of Zn and P (Kassab, 2005; Oseni, 2009) on the metabolic and biological activity and the possible stimulatory effect on photosynthetic pigments and enzyme activity which in turn encourage vegetative growth of the plants. The significant difference in mean number of primary branches exerted by the method of zinc fertiliser application under both under supplementary irrigation and dry land rainfed condition are in conformity with Singh *et al.* (2002), who found that the application of Zn and B as foliar spray increased the number of leaves, reduced leaf drop and hastened the flowering in papaya plant.

The delay in days to 50% flowering and pod formation following incremental zinc application as reported in this study under supplementary irrigation was possibly attributed to the cowpea leaf damaged following foliar application.This is however, contrary to earlier findings reported by Sajid *et al*. (2010) who reported less number of days to flowering for plants that received high concentration of Zn and low concentration of B as compared to untreated plants in control treatment. The contradiction might be related to the synergistic effects of Zn and B in the latter study. In the same vein, the higher canopy cover reported in this study following foliar spray in this study agrees with report by Asad *et al.* (2003) with foliar application of boron. The reduced value of canopy cover over time as the cowpea plants grow is as a result of the decrease in the distance between the two adjacent plants leading to increased soil cover over time.

5.2 Cowpea grain yield and yield attributes

Zinc is required for the biosynthesis of plant growth regulators, carbohydrate and N metabolism which leads to high yield and yield components (Taliee and Sayadan, 2000). Cakmak (2002) reported that increase in crop yield will depend on local soil conditions and method of zinc application. The reduced number of cowpea pods as well as pod dry weight per plant at higher rates of foliar zinc fertiliser application as compared to soil application was contrary to the findings by (Banks, 2004; Elballa *et al.,* 2004; Zeidan *et al*., 2006; Khorgamy and Farina, 2009) who obtained a significant increase in number of pods per plant and seed yield following zinc fertiliser application. Seifinadergholi *et al*. (2011) similarly reported that higher number of pods per plant was produced by foliar spraying at flowering and pod formation stages due to the significant effect on the reproductive organs, such as stamens and pollens.The variance observed in the present study may have been due to the burning of leaves, which possibly resulted in crop stress and our timing of the foliar spray. Maralian (2009) indicated that the timing of foliar Zn applications is an important factor that determines the effectiveness of the foliar applied Zn fertilizers in increasing grain Zn concentration. Similarly, Thalooth *et al*. (2006) stated that subjecting plants to water stress at pod formation stages of growth caused the highest reduction in number of pods/plant, pods dry weight and number of seeds index.

The significant effect of the method of zinc fertilizer application on the observed mean plant population at harvest following combined analysis of the data across the two trial sites was attributed to the serious depressive effects of burning by higher rates of zinc fertiliser application on cowpea leaves and possibly poor establishment of cowpea plants under supplementary irrigation at Ukulima. Such burning effect was worsened by the early spray of the zinc sulphate on the cowpea plants at Ukulima but was only mild under rainfed condition because of the delayed spray at Syferkuil. This is in agreement with findings by Yilmaz *et al*. (1997) who reported that the timing of foliar zinc application is an important factor for determining the effectiveness of the foliar applied Zn fertilizers in increasing grain zinc concentration.

The positive effect of soil application of zinc fertiliser on the total biomass and grain yield obtained under supplementary irrigation suggests that soil application may be the preferred method of application in order to obtain improve cowpea yield. This agrees with previous findings by Frossard *et al*. (2000) who reported that adding zinc to zinc deficient soils may result in both higher yields and zinc content of crops. Similarly higher, though not significant yield improvement in total biomass, grain yields and fresh pod weight was obtained with soil than foliar zinc fertiliser application under dry land rainfed condition in the present study. Oseni (2009) reported that higher yields is obviously the direct benefit to farmers, and higher zinc contents of crops have the potential to contribute to a reduction in the occurrence of zinc deficiency in humans when the crop is consumed.

Rengel *et al*. (1999) revealed that increasing the zinc content in soil solution can result in increased zinc concentrations in grain. Several other researchers have also revealed that the application of zinc fertiliser to the soil increased seed yield (Calhor, 2006; Amjad, 2004). Results from this study showed that the highest grain yield was achieved at 5 kg Zn ha^{-1} rates at Ukulima under supplementary irrigation. Zinc sulphate application beyond the 5 kg ha^{-1} rate resulted in 5 to 7% grain yield reduction at Syferkuil under rainfed condition and 9 to 22% grain yield reduction was obtained under supplementary conditions. The much higher percent grain yield reduction obtained at Ukulima under supplementary irrigation was attributed to the higher injury suffered by the cowpea plants particularly at higher zinc rates.

Clapp and Parham (1991) reported that fertilizer materials suitable for foliar application must be highly soluble in water, applied at low application rates and in dilute spray concentrations. Thus when zinc sulphate salt was applied in relatively high quantity, complete solubility was probably reduced thereby leading to excessively high solution concentration that exerted a burning effect on plant tissues, which consequently led to yield reduction. Similar leaf burn including on the margins of lower leaves even at low a concentration of 2% mono-potassium phosphate was reported by Chapagain (2001) following foliar application on tomato plants. The highly significant zinc level x methods of application interaction effect on total biomass and grain yield under supplementary irrigation conditions suggests that zinc is an important micronutrient and the method of application favoured increased growth and yields. Thalooth *et al*. (2006) spraying mungbean plants with zinc resulted in taller plants, greater number and weight of leaves and number of pods. The enhancement effect might be attributed to the favourable influence of the nutrient on metabolism and biological activity and its stimulating effect on photosynthetic pigments and enzyme activity which in turn improve vegetative growth of plants. Similarly, the strong and significant relationship between zinc rates and total above ground biomass, grain yield as well as pod fresh weight under supplementary condition from the quadratic polynomial regression suggests that application of higher zinc rates will result in increased total above ground biomass, grain yield and pod fresh weight due to higher zinc rates. Furlani *et al.* (2005) similarly reported a positive and significant regression coefficient for dry matter production among different maize cultivars at various zinc rates. The total haulm weight obtained following soil application was higher than that of foliar application under supplementary irrigation probably due to foliar burning in the latter while the comparable haulm yield under dry land condition was largely due to the absence of crop burning. The non-significant difference in the total haulm weight recorded at Syferkuil under dryland condition following incremental zinc rate agrees with earlier findings by Oseni (2009) who reported that the grain and haulm yields of cowpea were not significantly affected by P, Zn and their interactions.

The non-significant effect of method of zinc fertiliser application on harvest index reported under both supplementary irrigation and dry land rainfed condition was similar to the findings on the effect of placement of Sokoto phosphate rock reported by Sokoto and Singh (2007). However, the significant effect of the rates of zinc fertiliser application on harvest index under supplementary irrigation suggests the positive contribution of zinc toward cowpea seed size. Harvest index represents the proportion of photosynthates that is translocated into grain (Singh *et al*., 2011). The highly significant effect of the method of zinc application on shelling percentage with higher value following foliar application under supplementary irrigation condition similarly suggests the positive effect on seed sizes. Karikari (2000) reported that the shelling percentage of bambara groundnut landraces was significantly related to seed size with a high proportion of the pod mass contributed by the seed.

5.3 Nutrient content and uptake in different plant parts

Hemn (2013) reported that micronutrients such as iron and zinc are essential in plant for maintaining crop-physiological balance and that deficiency can markedly reduce crop's yield, and even cause cessation of plant growth. However, if the amount of micronutrients in soil cannot be readily absorbed by plants, it is better to use foliar application as it is more effective than soil application (Altındisl *et al*., 1998). Results from the present study revealed that foliar application tend to improve zinc content and uptake in leaves under dry land rainfed condition. The significant effects of variable zinc rates on crude protein, total N, P and iron contents of cowpea leaves, with higher values at Ukulima than Syferkuil may be attributed to water stress in Syferkuil during the course of the growing season. Maiti *et al*. (2000) reported that water stress can progressively decline the net photosynthesis rate associated with simultaneous decreased in free proline content. According to Krishna (1995) and Thalooth *et al*. (2006), foliar application of zinc greatly affect plant growth and productivity with significant positive effects on dry matter, seed and straw yield as well as the percent crude protein content in the seeds. The higher zinc concentration in leaves samples from foliar than soil applied zinc sulphate across the two trial sites was possibly attributed to better uptake, distribution and more efficient utilisation (Kassab, 2005; Mousavi, 2011). Earlier studies by Bubenheim *et al*. (1990) similarly revealed higher carbohydrate concentration and comparable protein content in older cowpea leaves to that in cowpea seeds. Furthermore, up to 4-folds increase in grain Zn concentration have been reported under field conditions depending on soil condition and the method or form of application (Bansal *et al*., 1990).

The increase crude protein, total nitrogen, phosphorus, iron and zinc uptakes in immature green pod samples following foliar application of zinc sulphate at Ukulima under supplementary irrigation condition reflects better zinc utilisation than soil application. The significant difference in the mean P, iron and Zn content as well as, iron and Zn uptake in immature green pods samples from the two trial sites might be attributed for environmental and inherent soil differences between the sites. Under supplementary irrigation condition at Ukulima, the soil type was sandy soil while under dryland condition at Syferkuil; the soil type was sandy loam. Marschner (1997) reported that zinc deficiency will likely occur in soils with organic matter content lower than 1%.

Thalooth *et al*. (2006) suggested that macro-nutrients play several physiological and biochemical roles such as chlorophyll formation, activation of enzymes, synthesis of proteins, carbohydrate metabolism and energy transfer. Climate factors such as temperature and moisture and plant nutrition all have an influence on biological yield (Falah, 2002). Nevertheless, the favourable growing conditions at Ukulima may possibly have arisen from the supplementary irrigation and the more efficient utilisation of the applied zinc as opposed to the dry Syferkuil growing conditions. Cakmak (2002) reported that plant exposed to environmental stresses requires additional supplies of mineral nutrients, particularly zinc, to minimize the adverse effects of stresses; hence, improving the mineral nutritional status of crops is of importance for minimizing detrimental effects of environmental stress factors on their growth and yield.

The highly significant treatments effect on the total N and P content in cowpea grain under supplementary irrigation condition was attributed to great influence on basic plant life processes such as mineral nutrients translocation (Mousavi, 2011). Ozturk *et al*. (2006) reported the highest zinc concentration in wheat grains during the reproductive and milk stages of grain development. According to Brohi *et al*. (2000), Zn is more efficiently used by plant if applied before and during leaf growth stage before the appearance of inflorescence. Swenson *et al*. (2009) revealed that foliar application before the booting stage resulted in significantly higher wheat yields. Similar to leaf and immature green pod samples, localities had a significant effect on the crude protein, total nitrogen, phosphorus, iron, zinc, total nitrogen uptakes, phosphorus uptakes, iron takes, iron uptakes of cowpea seeds or grains. The high increase in the total nitrogen, phosphorus and zinc content in cowpea seed/grain in soil than foliar application may be attributed to the condition on the leaf surface and possibly the elevated inherent zinc content in the soil, which probably limited the effectiveness of foliar application. Marschner (1997) reported that interception of nutrients by roots is an important uptake mechanism for soil immobile nutrients such as zinc.

CHAPTER 6

CONLUSIONS AND RECOMMENDATION

The application of 5 kg ha^{-1} of zinc sulphate appeared to be the optimum rate for both grain and fodder production when soil applied across both trial sites. It was also evident that foliar application of zinc rates beyond 5 kg ha^{-1} resulted in a significant grain yield decrease at both trial sites but worse at Ukulima under supplementary irrigation. Zinc application at Syferkuil under rainfed condition exerted no positive effect on total above ground biomass, grain yield and pod fresh weight but gave inconsequential and depressive effect on plant population. The interaction between zinc level x methods of application showed a highly significant effect on the total biomass and grain yield under supplementary irrigation conditions. The quadratic polynomial regression similarly showed strong and significant relationship between zinc rates and total above ground biomass, grain yield as well as pod fresh weight under supplementary condition. Quantitative estimates of the optimum zinc rates obtained from the quadratic equations were beyond the rates evaluated; and varied greatly depending on the yield component of interest.

The evaluated zinc sulphate rates though showed a poor relationship with the yield variables but resulted in higher growth and yield. Under supplementary irrigation at Ukulima, zinc sulphate application rate higher than 25 kg ha^{-1} might be necessary due to the sandy nature of the soil; hence, further trials with higher rates are needed to validate the data obtained from the model. For nutrient analysis of leaves, foliar application resulted in increased zinc content and uptake on leaves, pods and seeds/grain as compared to soil application under dry land rainfed condition. These nutrients and nutritional compositions were higher in samples from Ukulima under supplementary irrigation than those from Syferkuil under rainfed dry land condition. Based on the quadratic model used in this study, the optimum zinc rate required to guarantee high cowpea yield and zinc-rich grain and leaf content at both trial sites is highly variable; and thus requires further study for validation. It is therefore recommended that, foliar spray of high doses of zinc sulphate must be split applied so as to address zinc deficient problem in soils and also promote increased growth and zinc-rich leaf and grain yield.

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APPENDICES

Appendices 1: P-Values for ANOVA to determine effect on the mean number of primary branches and trifoliate leaves per plant at 10 WAP

Sources of variation	Ukulima		Syferkuil	
	Number of primary branches	Number of trifoliate leaves	Number of primary branches	Number of trifoliate leaves
Zinc rates	0.001	0.000	0.277	0.832
Method of application	0.007	0.001	0.336	0.625
Zinc rates x Method interaction	0.111	0.182	0.324	0.606

Appendices 2: P-Values for ANOVA to determine effect on phenological growth attributes under supplementary irrigation at Ukulima

Sources of variation	Canopy cover prior to flowering (cm)	Canopy cover at 50% flowering (cm)	Canopy cover at 50% pod formation (cm)	Day to 50% pod formation	Day at 50% flowering
Zinc rates	0.177	0.005	0.005	0.143	0.028
Method of application	0.255	0.008	0.006	0.011	0.008
Zinc rates x Method interaction	0.061	0.295	0.073	0.301	0.141

Appendices 3: P-Values for ANOVA to determine effect on selected growth attributes prior to plant full maturity under supplementary irrigation and rainfed dry land condition

Sources of variation	Ukulima				Syferkuil			
	Fresh pod weight (g)	Dry pod weight (g)	Fresh biomass weight (g/plant)	Dry biomass weight (g/plant)	Fresh pod weight (g)	Dry pod weight (g)	Fresh biomass weight (g/plant)	Dry biomass weight (g/plant)
Zinc rates	0.002	0.004	0.053	0.023	0.558	0.168	0.821	0.656
Method of application	0.007	0.016	0.066	0.044	0.259	0.838	0.049	0.113
Zinc rates x Method interaction	0.062	0.551	0.001	0.033	0.484	0.234	0.598	0.692

Appendices 4: P-Values for ANOVA to determine effect on cowpea grain yield and yield attributes obtained at harvest under supplementary irrigation at Ukulima

Sources of variation	Plant population (ha^{-1})	Number of pods/ plant	Grain yield (kg ha^{-1})	Fodder weight (kg ha^{-1})	Haulm weight (kg ha^{-1})	Total above ground biomass (kg ha^{-1})	Harvest index (%)	Shelling percentage
Zinc rates	0.565	0.028	0.001	0.831	0.008	0.171	0.024	0.026
Method of application	0.773	0.003	0.003	0.473	0.002	0.005	0.118	0.000
Zinc rates x Method interaction	0.689	0.758	0.003	0.027	0.004	0.002	0.0140	0.014

Appendices 5: P-Values for ANOVA to determine effect on cowpea grain yield and yield attributes obtained at harvest under dry land rainfed condition at Syferkuil

Sources of variation	Plant population (kg ha^{-1})	Grain yield (kg ha^{-1})	Fodder weight (kg ha^{-1})	Haulm weight (kg ha^{-1})	Total above ground biomass (kg ha^{-1})	Harvest index (%)	Shelling percentage
Zinc rates	0.415	0.832	0.831	0.713	0.315	0.558	0.148
Method of application	0.050	0.625	0.473	0.774	0.297	0.747	0.946
Zinc rates x Method interaction	0.638	0.606	0.027	0.357	0.354	0.317	0.112

Appendices 6: P-Values for ANOVA to determine effect of treatments on selected nutrient content and uptake in harvested leaves samples under dry land rainfed conditions at Syferkuil

Sources of variation	Nutrients content					Nutrients uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Zinc rates	0.323	0.322	0.586	0.796	0.700	0.261	0.448	0.649	0.734
Method of application	0.407	0.406	0.699	0.730	0.004	0.315	0.612	0.972	0.010
Zinc rates x Method interaction	0.090	0.0900	0.091	0.775	0.808	0.201	0.324	0.540	0.862

Appendices 7: P-Values for ANOVA to determine effect effects on selected nutrient content in harvested leaves samples under supplementary irrigation condition at Ukulima

Sources of variation	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})
Zinc rates	0.553	0.553	0.332	0.234	0.708
Method of application	0.475	0.475	0.173	0.094	0.614
Zinc rates x Method interaction	0.501	0.501	0.818	0.055	0.392

Appendices 8: P-Values for ANOVA to determine effect of methods and rates of zinc application on selected nutrient content and uptake as well as nutritional content in immature green pods under dry land rainfed condition at Syferkuil

Sources of variation	Nutrients content					Nutrient Uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Zinc rates	0.518	0.518	0.834	0.881	0.453	0.574	0.398	0.766	0.132
Method of application	0.860	0.860	0.365	0.755	0.089	0.952	0.471	0.830	0.716
Zinc rates x Method interaction	0.320	0.320	0.710	0.675	0.759	0.304	0.606	0.681	0.817

Appendices 9: P-Values for ANOVA to determine effect of method of application and zinc rates on selected nutrient content and uptake as well as nutritional content in immature green pods under supplementary irrigation condition at Ukulima

Sources of variation	Nutrients content					Nutrient Uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Zinc rates	0.362	0.3624	0.1088	0.8026	0.074	0.023	0.063	0.3343	0.258
Method of application	0.035	0.0346	0.0173	0.7710	0.134	0.067	0.085	0.0295	0.033
Zinc rates x Method interaction	0.859	0.859	0.893	0.751	0.423	0.151	0.190	0.698	0.223

Appendices 10: P-Values for ANOVA to determine effect of method of application and zinc rates on selected nutrient content and uptake in cowpea seeds/grains under dry land rainfed condition at Syferkuil

Sources of variation	Nutrients content					Nutrient Uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Zinc rates	0.276	0.277	0.197	0.242	0.431	0.589	0.440	0.190	0.638
Method of application	0.181	0.180	0.094	0.531	0.316	0.315	0.098	0.513	0.468
Zinc rates x Method interaction	0.596	0.596	0.721	0.523	0.424	0.791	0.606	0.511	0.354

Appendices 11: P-Values for ANOVA to determine effect of method of application and zinc rates on selected nutrient content and uptake in cowpea seeds/grains under supplementary irrigation condition at Ukulima

Sources of variation	Nutrient content					Nutrient uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Zinc rates	0.958	0.958	0.755	0.820	0.151	0.050	0.017	0.486	0.464
Method of application	0.347	0.345	0.707	0.658	0.564	0.008	0.001	0.174	0.131
Zinc rates x Method interaction	0.347	0.347	0.325	0.305	0.735	0.052	0.022	0.127	0.222

Appendices 12: P-Values for ANOVA to determine effect of Variation in the mean contents of crude protein and selected nutrient in harvested leaves samples over different treatment factors across the two trial sites

Trial sites	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})
Locality	0.006	0.005	0.012	0.000	0.532

Appendices 13: P-Values for ANOVA to determine effect of Variation in the mean contents of crude protein and selected nutrient in harvested immature green pods and dried grain across the two sites

Sources of variation	Nutrient content					Nutrient uptake (mg kg^{-1})			
	Crude protein (%)	Total Nitrogen (%)	Phosphorus (%)	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Total Nitrogen	Phosphorus	Iron	Zinc
Immature green pods									
Locality	0.947	0.947	0.000	0.000	0.000	0.080	0.184	0.009	0.000
Cowpea grains									
Locality	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.007	0.696

Appendices 14: Peer review abstract of paper presented as oral at the 9th African Crop Science Society Conference, Entebbe-Uganda 14-17 October 2013

RESPONSE OF COWPEA TO VARIABLE RATES AND METHODS OF ZINC APPLICATION UNDER DIFFERENT FIELD CONDITIONS

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Abstract

A zinc fertilizer trial was planted at two markedly distinct locations during 2012-summer growing season to determine the effect of different methods and rates of application on growth and yield component parameters of cowpea under dry land rainfed and supplementary irrigation. Treatments consisted of six zinc rates (0, 5, 10, 15, 20 and 25 kg ha^{-1} $ZnSO_4$) and two methods of application (soil and foliar). The trials at both sites were laid out in a split-plot arrangement fitted into a randomized complete block design (RCBD) with four replicates. Results obtained revealed that soil application resulted in approximately 2% and 5% reduction in plant population relative to foliar application under supplementary irrigation and rainfed condition, respectively. Total above ground biomass yield of 6219 kg ha^{-1} and fresh pod weight of 142.3 g/plant were obtained when zinc was soil applied under rainfed condition compared to 6019 kg ha^{-1} and 138.0 g/plant for total above ground biomass yield and fresh pod weight, respectively when foliar applied. Results under supplementary irrigation revealed that soil application gave a total above ground biomass yield of 6298 kg ha^{-1} and pod fresh weight of 150.9 g/plant while foliar application gave total above ground biomass yield and pod fresh weight of 4791 kg ha^{-1} and 124.0 g/plant, respectively. Soil application gave a significantly higher grain yield of 2251 kg ha^{-1} than the 1503 kg ha^{-1} for foliar application under supplementary irrigation. A higher but not significant grain yield of 2771 kg ha^{-1} than 2723 kg ha^{-1} was obtained for soil and foliar zinc application, respectively under rainfed condition. Application of zinc fertilizer at a rate beyond 5 kg ha^{-1} resulted in a substantial grain yield reduction

under both rain-fed and supplementary irrigation. Thus, this rate appeared optimum when soil applied for both grain and fodder cowpea production under these conditions. Results of laboratory analyses of both edible pod and grain tissue samples are underway to determine the zinc content for appropriate recommendations.

Key words: Cowpea production; micronutrients; improved nutrition; foliar fertilizer application; dry land farming.

Appendices 15: Peer review abstract of paper presented as oral at the 3rd Faculty of Science and Agriculture Research Day, Bolivia Lodge, Polokwane-South Africa 3-4 October 2013

RESPONSE OF COWPEA TO VARIABLE RATES AND METHODS OF ZINC APPLICATION UNDER RAINFED AND SUPPLEMENTARY IRRIGATION CONDITIONS

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Abstract

A zinc fertilizer trial was planted at two markedly distinct locations during 2012-summer growing season using cowpea variety ARC-GCI-CP-6 as test crop. The trial at one of the sites was planted under rainfed condition while the second was planted under supplementary irrigation. Treatments consisted of six rates (0, 5, 10, 15, 20 and 25 kg ha^{-1}) and two methods (soil and foliar) of zinc sulphate fertiliser application; and were laid out in a split-plot arrangement fitted into a randomized complete block design, with four replicates. Plant vigour, numbers of primary branches and the number of trifoliate leaves were measured on four tagged plants in each plot at 6 weeks after plant emergence. Twenty fully developed fresh immature pods were randomly harvested from the two middle rows of each plot at 12 WAP and weighed. Fodder and grain weights were taken at harvest. Growth and yield data generated were subjected to analysis of variance using Statistix 8.1 software, while differences between treatment means was separated using the Tukey's test at 5 % level of significance.

Results obtained revealed that only zinc application rate exerted a significant effect on plant vigour ($P \geq 0.05$) under rainfed condition while both the method and rates of zinc application exerted significant ($p<0.05$) effects on the number of leaves, number of branches and plant vigour under supplementary conditions. Fresh pod weight of 142.3 g/plant and 138.0 g/plant, respectively were obtained when zinc was soil and

foliar applied under rainfed condition while 150.9 g/plant and 124.0 g/plant, respectively under irrigation. Dried fodder weight following soil and foliar application under both rainfed and irrigated field conditions are comparable. A higher but insignificant grain yield of 2771 kg ha^{-1} than 2723 kg ha^{-1} was obtained for soil and foliar zinc application, respectively under rainfed condition. Zinc sulphate application beyond 5 kg ha^{-1} rate resulted in 5 to 22% grain yield reduction in both fields. Soil application appeared to improve growth and yield of cowpea better than foliar application. A regression analysis on grain yield and relevant yield parameters is still underway to be performed to establish the optimum rate.

Appendices 16: Peer review abstract of paper presented as poster at the 14th Combined Congress, Rhodes University, Grahamstown- South Africa 20- 23 January 2014

OPTIMISING ZINC FERTILIZATION RATES FOR COWPEA PRODUCTION UNDER SUPPLEMENTARY IRRIGATION AND RAINFED CONDITIONS

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INTRODUCTION

Zinc (Zn) deficiency has been described as one of the major widespread micronutrient disorders that contribute to public health problems in developing countries. Hotz and Brown (2004) reported that more than 19.7% of South Africa's population is at risk due to inadequate Zn intake. The problem is exacerbated by the high prices of micronutrients-rich foods and exotic leafy vegetables that are locally available. This study determined the optimum zinc rate that would result in high zinc accumulation in cowpea plant tissue under different field conditions for improved human and animal diets.

MATERIALS AND METHODS

Field trials with cowpea variety IT00K-1217 were conducted at Ukulima farm (sandy soil), Modimolle under supplementary irrigation and at the University of Limpopo experimental farm (loamy soil), Syferkuil under rainfed conditions during the 2012/13 season. The average rainfall at Ukulima is higher, but the temperatures lower than at Syferkuil. Pre-planting soil analysis from Syferkuil indicated a much higher (2.76 mg kg^{-1} Zn) content than at Ukulima. Treatments consisted of six blanket zinc rates (0, 5, 10, 15, 20 and 25 kg ha^{-1}) applied to the soil or as a foliar application. The experiments were laid out in split plot arrangements fitted into a RCBD with four replicates. Zinc was applied as $ZnSO_4$ (38.5% Zn) while 30 kg P ha^{-1} was applied to eliminate P constraints. Twenty fresh immature cowpea pods were randomly harvested from each plot at twelve weeks after planting and weighed. Grain and fodder yields as well as total biomass were obtained at harvest. Data were subjected to analysis of variance using Statistix 8.1 while treatment means were separated using Tukey's test at 5% probability level. Response variables were modeled using quadratic polynomials to estimate the optimum zinc rate.

RESULTS AND DISCUSSION

Treatments had a highly significant effect on grain yield (P = 0.001) and fresh pod weight (P = 0.002) under supplementary irrigation only. The yield components under supplementary irrigation had a correlation of 0.70 to 0.94 but varied between 0.03 and 0.80 under rainfed condition. Based on the quadratic models, total biomass (4897 kg ha^{-1}) and grain (1602 kg ha^{-1}) yields were optimised at an estimated zinc rate of 54.7 and 33.4 kg ha^{-1}, respectively under supplementary irrigation while the total biomass (5913 kg ha^{-1}) and grain (2696 kg ha^{-1}) yields were obtained at an estimated optimum zinc rates of 20.1 and 26.8 kg ha^{-1}, respectively under rainfed condition. Similarly, fresh pod weight of 155 g and 140 g per twenty pods per plot was optimised at 25.2 kg ha^{-1} and 8.5 kg ha^{-1} zinc application rate under supplementary irrigation and rainfed condition, respectively.

CONCLUSIONS

Quantitative estimates of the optimum zinc rates obtained from the quadratic equations were beyond the rates evaluated; and varied greatly depending on the yield component of interest. Under supplementary irrigation, zinc sulphate application rate of more than 25 kg ha^{-1} might be necessary due to the sandy nature of the soil; thus, further trials with higher rates are needed to validate the data obtained from the model.

REFERENCES

Holtz C, Brown KH. 2004. Assessment of the Risk of Zinc Deficiency in Populations and Options for its Control. *United Nations University Press, Tokyo.*

Keywords: Cowpea, improved nutrition, supplementary irrigation condition, zinc deficiency.