DECLARATION

I Mônea Lina Adelino Mucavêa, declare that this thesis is a result of my own original effort and work, and to the best of my knowledge, the findings have never been previously presented to the University of Malawi or elsewhere for the award of any academic qualification. Where assistance was sought it has been accordingly acknowledged.

Mônea Lina Adelino Mucavêa

Signature:…………………………………………….

Date:………………………………………………..

CERTIFICATE OF APPROVAL

We, the undersigned, certify that this is a result of the author's own work, and that to the best of our knowledge, it has not been submitted for any other academic qualification within the University of Malawi or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on….

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DEDICATION

This study is dedicated to my father and my mother Adelino Ribaue and Rosalina Ribaue for giving me the wings to fly and giving me the reason to fight. To my brother and sisters Nimone, Marcelino, Tabia, Marcilia and Paciencia.

To my nephews Jamal and Elieser.

Parents, because of you, I can.

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Initially, I would like to thank God Almighty for His mercy and unconditional love upon my life. I have experienced His blessings all my life and the Lord has been good all the time.

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Lastly, to the crop science class of 2012 to 2014, “You were such a wonderful company.”

God bless you all.

ABSTRACT

Drought and soil fertility are some of the major factors limiting crop yield especially in crop legumes. Six on-station trials were conducted to determine nutrients limiting the grain yield and yield component in common beans (*Phaseolus vulgaris* L.) under drought and non-drought conditions at Kandiyani and Chitedze Research Station. Two trials were conducted at Chitedze Research Station under rainfed conditions: one using a climbing bean variety (MAC 53) and another using bush bean variety (SUG 131). The trials were repeated at Kandiyani under irrigation: one set of bush and climbing bean (2 trials) were evaluated under adequate moisture up to physiological maturity and another set (2 trials) was evaluated under moisture stress by cutting the water supply soon after flowering to simulate terminal drought.

The experiments were laid out in a split-plot treatment arrangement with 3 replicates. In each replicate 9, main plots (macronutrient factors) were allocated at random to each replicate, and within the main plot, 4 subplots (micronutrient factors) were allocated at random making a total of (9x4) 36 treatments in each replication. The macro-nutrient factors included: (1) control; (2) N; (3) P ; (4) K; (5) Ca; (6) N2-fixation –CIAT 899 Rhizobium (Rz); (7) NP, (8) NPRz; and (9) NPK. The sub-plots were: (1) control; (2) B; (3) Mo; and (4) ZnS.

There were significant interaction among macronutrient and micronutrient on grain yield. Nitrogen, Phosphorus, Molybdenum with rhizobium inoculant (NPRz + Mo) resulted in significantly increased grain yield of beans, days to flowering, number, fresh weight of nodules number of pods and 100 seed weight.

Across water regime analysis on climbing beans showed that the macronutrients application had highly significant effects ($P<0.001$) on the number of days to flowering, number of pods per plant and grain yield per hectare, while macro-micronutrient combination had significant effect at $P=0.005$ level on days to flowering and highly significant effect ($P<0.001$) on the number of pods per plant.

In terms of drought tolerance efficiency (DTE) and drought susceptibility, P fertilizer treatment was observed to influence high drought tolerant efficient (DTE) also with smaller percentage of reduction (2%) under drought stress. However, NPK + Mo treatment was the best with smaller drought susceptibility index (DSI) on bush beans. Under climber beans, N+P and N+P+Rz were observed to be the best with high drought susceptibility index (DSI) among the 36 treatments.

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LIST OF ABBREVIATIONS AND ACRONYMS

ARET	Agriculture Research and Extension Trust
B	Boron
Ca	Calcium
Chl	Chlorophyll
CIAT	International Centre for Tropical Agriculture
DAP	Days after planting
DII	Drought intensity index
DS	Drought stress
DSI	Drought susceptibility index
DTE	Drought Tolerance Efficiency
FSSA	Fertilizer Society of South Africa
HI	Harvest index
Mo	Molybdenum
MoAFS	Ministry of Agriculture and Food Security
N	Nitrogen
S	Sulfur
WW	Well watered
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

1.1 Origin of beans

Common beans (Phaseolus vulgaris L) are believed to originate from Mesoamerica, this comprise five species of genus Phaseolus.sp namely: Phaseolus coccineus, Phaseolus acutifolius, Phaseolus lunatus, Phaseolus polyanthus and Phaseolus vulgaris (Goldsworthy andFisher, 1984).These species grow well under different environments ranging from temperate, arid and semi-arid, dry and humid warm as well as semi-temperate humid climatic condition. The Phaseolus vulgaris grows in all climates but commonly in warm temperate climate (Edith et al., 1997).

Debouck et al.; 1996 considered Phaseolus vulgaris L. to be native to the Americas whereby from central western Mexico to northern Argentina it is found in natural state of wild ancestral types of Phaseolus vulgaris. In Africa, common beans were probably introduced by Portuguese and reached Malawi through Mozambique and the coast hundred years ago (CIAT, 1981). The main common bean growing districts in Malawi are: Chitipa, Rumphi, Mzimba, Dowa, Nchitsi, Dedza, Ntcheu, Zomba and Thyolo. This crop is the second after groundnuts in total production in Malawi.

1.2Importance and use of beans

Common bean (Phaseolus vulgaris L.) is the world’s most important food legume. This is considered as a nearly perfect food mainly because of its high protein content and abundant fiber, complex carbohydrates, and other daily food needs such as vitamins (folate) and minerals (Cu, Ca, Fe, Mg, Mn, Zn). Among major food legumes, common bean (Phaseolus vulgaris L.) is considered the third most important worldwide, after soyabean [Glycine max (L.) Merr.] and peanuts (Arachis hypogaea L.). Among the pulses (annual leguminous food crops that are harvested as dry seeds) the common bean is by far the most important (Singh., 1999; Miguel et al., 2012). Common beans also play an important role in human health that as it can reduce the risk of colon cancer and heart diseases. It can also regulate the level of glucose and insulin in the blood (Prolla et al.,2010).

In Latin American countries, national per capita consumption of beans is typically between 12 and 18 kg per year, and this consumption does not reflect differences in urban and rural areas (Broughton et al., 2003). In Africa common bean is considered the second most important source of dietary protein and the third most important source of calories for lower income African households after cassava and maize (Pachico, 1993).In Malawi beans are considered cheaper source of protein compared with animal or fish protein. A common bean (Phaseolus vulgaris L.) is also high in lysine and amino acids compared with the staple carbohydrate food crops of Malawi, like maize, rice and cassava. One the advantages of common beans production and use is the short production cycle, where some varieties can take three months to mature (Mwale et al.; 2008).

1.3 Beans growth habit

The bean crop growth habit characteristics are used to classify bean varieties. Morphologically the bean plant is classified as determinate when the terminal meristem bud is the reproductive part of the plant or indeterminate when the meristem buds are vegetative. In the indeterminate habit, stem elongation cease when the terminal flowering racemes of the main stem or lateral branches have developed. Indeterminate habit, flowering and pod filling continue simultaneously or alternately as long as the conditions of proper temperature and moisture availability are there (CIAT, 1981).

The terminal meristem is found at the tip of stem and is the origin of cell division. In common beans plant, this type of meristem is vegetative but may become an inflorescence. Oscar *et al.*(2006) classified traits of common beans in four growth habits: type I as determinate bush; type II as indeterminate bush; type III as indeterminate semi-climbing and type IV as indeterminate climbing. Goldsworthy and Fisher (1984), supported that the determinacy and indeterminacy are also determinate by number of main stem nodes between flowering to maturity; the weight of seed; and number of branches. Type II,III and IV have indeterminate habit , type II produces more branches; and heavy seeds are produced by common beans type I and IV.

1.4 Beans production status

The common bean is known to be traditionally grown by smallholder farmers, usually in complex patterns on the farms for instance in rotation, alley crop or intercropping with maize, sorghum, cassava, banana or other crops. However, large scale production, with proper mechanization, where some farms plant over a thousand hectares to common bean has taken root. The total global common bean production exceeds 23 million tons (MT), of which 7 million are produced in Latin America and Africa (Broughton *et al.,* 2003).

Cultivation of common bean in Africa is done at high altitude levels. Katungi *et al.* (2009) reported that in terms of production Kenya comes second after Uganda, thus the leader of common bean production is Uganda followed by Kenya and then Tanzania. Malawi is on eighth position.

Table1.1: Ten producers of common beans in term of area and production (2000-2007) in Africa

Country	Average area (Ha)	Average prod (Tons)	Average yield(Kg/ha)
Kenya	910478	412381	0.45
Uganda	794375	478625	0.60
Tanzania	373125	285414	0.76
Rwanda	290391	92786	0.32
Angola	340055	231881	0.68
Burundi	249375	229607	0.92
DRC	205958	110404	0.54
Malawi	197607	87593	0.44
Ethiopia	188000	143414	0.76
Madagascar	81096	77273	0.95

According to Ministry of Agriculture and Food Security (MoAFS) in Malawi bean production increased for the past nine seasons 1999 to 2008 but declined in 2008/2009 growing season. In the years under consideration, yield per hectare was variable. Only production showed increasing tread and declined in 2008/2009 season (Table 1.2).

Table 1. 2: Estimated bean production for the past ten seasons in Malawi

Season	Area (Ha)	Yield (Kg/ha)	Production (mt)

1999/00	171,775	436	74,909
2000/01	219,808	496	108,928
2001/02	233,476	437	102,045
2002/03	239,476	459	109,832
2003/04	204,514	376	76,964
2004/05	233,845	367	85,759
2005/06	242,568	486	117,808
2006/07	268,688	494	132,689
2007/08	268,995	483	129,948
2008/09	32,760	686	22,467
Average	211,598	472	96,135

1.5 Definition of drought, drought stress and physiological mechanism of adaptation to drought

Drought is a meteorological term and is commonly defined as a period without significant rainfall. Generally, drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation (Jaleel *et al*., 2009).

Smirnoff, (1993); Jaleel *et al., (*2007d) considered drought stress to be a moderate loss of water, which leads to stomata closure and limitation of gas exchange. Desiccation is much more extensive loss of water, which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalyzed reactions. In many cases, loss of water in sensitive plants or crops results in decrease of yield or death of whole plant due to cessation of catalyzed reactions. When plants are able to survive and produce in periods of dry weather, the mechanism is called drought resistance, which can be grouped into three categories: drought escape; drought avoidance; and drought tolerance (Levitt, 1972).

Drought escape: Is defined as the ability of the plant to complete its life cycle before severe soil and plant water deficits occurs, the mechanism involves early maturity and flowering (Amede *et al.;* 2004).

Drought avoidance: When plants can avoid drought through their ability to maintain relatively high tissue water potential, despite a shortage of soil moisture. This is achieved through increased rooting depth, an efficient root system and increased hydraulic conductance. This mechanism ensures that the plant maintains higher water status during that period of drought stress and this can also be achieved by reducing transpiration from aerial parts (Levitt; 1980).

Drought tolerance: when Plants have the ability to withstand water deficit with low tissue water potential. This is achieved through maintenance of turgour through osmotic adjustment (a process which induces solute accumulation in the cell); increase in cell elasticity and decrease in cell size; and desiccation tolerance by protoplasmic resistance (Beebe *et al.,* 2013)

1.5.1 Categories of drought

Three categories of drought defined by Ludlow and Muchow (1990) are: early season; intermittent; and terminal depending on when it occurs during crop development. There is a situation whereby rain comes but it is not enough for seed germination and crop establishment. This type of drought is called early season drought which causes poor germination, seed rot and which eventually lead to poor plant stand in the field. Yield obtained after early season drought becomes lower than when the soil is well watered with adequate moisture for plant growth and development (Shao *et al.;* 2001). Manjero et al. (2007) noted that at situation of early season drought when withholding irrigation two weeks after germination, common beans seed yield was lower than yield under normal water supply. All yield components were reduced at vegetative stage due to early water stress, and this affected grain yield which is a product of several yield components.

Intermittent drought comes about as result of sporadic rainfall that causes intervals of drought, this happen during the vegetative or reproductive growth stages. The nature of this rainfall is unpredictable and leads to marginal yields in potentially valuable land (Singh 1995). This type of drought can also affect the plant at different stages of development. Depending on the intensity and frequency of occurrence, intermittent drought affects biomass accumulation in the seed yield for almost several legume crops (Subbarao, 1995).

Terminal (end-of-season) drought occurs during reproductive stage of crop cycle when the crop is flowering or at mid pod filling. This type of drought has been considered more stressful than the intermittent drought; the crop encounters moisture stress which can reduce final grain yield. In chickpea study, late-terminal drought under rainfed had shorter reproductive growth duration and faster maturity with a decrease of seed yield by 49% (Nezar *et al*., 2009).Research done reported that under terminal drought yield was reduced on common beans due to disease pressure, performance was reduced by attack from *Macrophomina phaseolina* (Tassi Goid), the causal organism of charcoal rot disease of bean (Mark *et al.*, 2004).

Malawi has been experiencing long dry spell and sometimes droughts, that have seriously reduced crop production by 1.7 percent of the country is gross domestic product on average year. The country experiences also a prolonged mid-season dry spell accompanied by high temperature that causes soil moisture content reduction and consequent plant water deficit (Karl *et al.;* 2010).

1.6 Common bean in Malawi

The common bean (*Phaseolus vulgaris* L.) is an important grain legume crop in Malawi where it is grown by small holder farmers for food as well as low income families and educational institutions. The greatest advantage of dry beans is the ease to conserve by small- scale farmers and it is relatively cheaper compared to meat, since its protein content can replace meat and fish for a long period (Mwale *et al*., 2009).

According to a study by Chirwa et al. (2007) common beans in Malawi is grown by over 80% of the Malawian farming population and the cultivation is usually done in different cropping systems, for example pure and mixed crop stands whereby the farmer mix with maize; relay cropping usually in the field where maize has been produced and harvested, under irrigation usually after rice harvesting and in *dimba* gardens, with residual moisture.

1.7 Fertilizer response and requirement on common beans in Malawi

In most east and southern African countries, low soil fertility is limiting the yield in most beans production. Prolonged degradation by erosion and repeated removal in crop harvest without replacing nutrients removed has become hectic factor that affects yield of common beans in Malawi and elsewhere. Authors reported that among fertilizers or nutrients required on common beans production, N and P deficiency in the soil can reach 60 to 80%; respectively (Margaret et al., 2014). Among all fertilizers needed by common beans crop in Malawi, NPK fertilizer is most known and used by farmers.

1.8 Problem statement and justification

Drought and low soil fertility are primary constraints to crop production throughout the developing countries. This is especially true of common bean, which in many African countries is typically grown by smallholder farmers in marginal environments with low level of additional farm inputs application. Katungi *et al.,* (2009) reported that although bean production area in Malawi has increased by 50% between 2001 to 2007 from 145,000 to 220,000 hectares; respectively; following a domestic demand, the total bean production is still low, because productivity is constrained by biotic factors which include insects, diseases, weeds and abiotic constraints which are imposed by the environment such as soil, climate and water.

Abiotic stresses are the most important constraints that adversely affect bean yield. In the tropics, bean yield often is below 1000kg/ha (Buatare *et al.,* 2011). Drought is one of the most abiotic factors limiting agriculture today and it limits the productivity of bean in tropical lowlands of Central and South America and Africa (Beebe *et al.,* 2008). It is estimated that 60% of common bean production in the developing world occurs under conditions of significant drought stress (Graham and Ranalli, 1997). Drought reduces the expression of characteristics in common bean; notably acceleration of the maturity of the crop with reduction of reproductive phase, seed size and grain yield. It also affects nodulation and is known to lower the number of pods during flowering (Nielsen and Nelson, 1998; Molina *et al.,* 2001)

In addition, soil fertility is also a major problem constraining crop production in Malawi. The increase of human population has led to diminishing land size and this coupled with declining soil fertility with nitrogen being the most limiting nutrient followed by phosphorus, has exacerbated the problem (Makumba, 1997).

The challenge that confronts Malawi is to identify tolerant varieties of common bean to drought stress and identify nutrients which are limiting factors on yield and yield components. Demand of dry bean is still there and Malawi imports some of its beans from Tanzania (Tchale, 2002). Thus this study will focus on determining limiting nutrients to grain yield and yield components of common bean (*Phaseolus vulgaris* L.) under drought and non-drought conditions.

1.9 Main Objective

To determine limiting nutrients to grain yield and yield components of common beans (*Phaseolus vulgaris L*.).

1.9.1 Specific Objectives

1. To determine the grain yield and yield components responses of bush and climbing bean types to macronutrients and micro-nutrients application under drought and non-drought stress conditions.

2. To determine the grain yield and yield components responses of bush and climbing beans type under:

a) Combination of macro-nutrients application

b) Combination of micronutrient application

c) Interaction of macro and micro-nutrient application.

3. To determine the relationship between yield components and grain yield, and among yield components.

1.9.2 Null Hypothesis

1) The macro and micro-nutrients application have no effect on grain yield and yield components in bush or climbing bean under drought or no drought stress.

2. a) The combination of macro-nutrients application have no effect on grain yield and yield components in bush or climbing beans.

2. b) The combination of micro-nutrients application have no effect on grain yield and yield components in bush or climbing bean.

2.c)The macro-nutrients and micro-nutrient interaction have no effect on grain yield and yield components in bush or climbing bean.

3) There is no relationship between yield components and grain yield and among yield components.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Production requirements of common beans

According to Gómez (2004), common bean is a warm-season crop with an optimum temperature of about 24°C., the crop does not tolerate frost or long periods of exposure to near-freezing temperatures at any stage of growth. Common bean does not tolerate high temperatures (>30ºC) either, as such temperatures can cause flower blasting, and dropping of buds. Well drained soils for germination are required for common bean production as the crop is sensitive to both moisture stress and water logging (Organic Seed Alliance www.seedalliance.org). In general, common bean grow better in well drained soils with a depth of at least 90 cm, which have no nutrient deficiencies. Sandy, loam, sandy clay loam or clay loam with clay content of between 15 and 35 % are very suitable for bean production. With sandy soils, problems of low soil fertility or nematode damage may occur. Soil of pH 5.8 to 6.5 are suitable for common bean, as the crop is very sensitive to acidic (pH< 5.2) soils. The crop will also not grow well in soils that are compacted, too alkaline or poorly drained (du Plessis *et al.,* 2002).

The common bean requires moderate amounts of water (300-600)mm. Adequate moisture during early part of the season is necessary and essential especially so during the pod-filling stage (during and immediately after flowering); during this stage the soil should not hold less than 60% field capacity to ensure proper moisture availability (Katungi *et a*l., 2009). Dry weather is desirable for the maturation of the bean crop and for harvesting (Free, 1993).

2.2 Nutrient requirement of common beans

2.2.1 Macronutrients

2.2.1.1 Phosphorus (P)

Phosphorus is the elements most often limiting in tropical soils. Legumes are especially limited by poor P availability; as it is one of the most important nutrients significantly affecting plant metabolism and growth (Tesfaye et al., 2007). The high requirement for P in legumes is consistent with the involvement of P in the high rates of energy transfer that must take place in the nodule (Israel, 1987). Under P limiting conditions, legumes may lose the distinct advantage of an unlimited source of symbiotic N (Luscher*et al.*, 1998), soluble sugar and amino acids in common beans plant that may also decrease in vegetative organs (leaf, root and nodules) (Olivera *et al*.,2004).

Amongst the functions of P in legumes is growth of extensive root system and, seedling development. Phosphorus application had significant enhancement on a number of parameters on pea production such as of biomass, branches, shoot/root dry weight, number of pods and seed yield (Erman *et al*., 2009). Similarly; Turuko and Muhammad (2014) reported that application of P fertilizer increased number of pods per plant on common beans over the control; increases also include dry matter yield accumulation.

2.2.1.2 Nitrogen (N)

The common beans (*Phaseolus vulgaris* L.) utilize inorganic soil N or applied fertilizer N and N_2 fixed by a symbiotic relationship with *Rhizobium phaseoli*, both sources seem necessary for maximum yield (Franco et al., 1979). Studies have shown that the symbiotic N_2 fixation on common beans does not provide sufficient N for maximum yield as compared with soy bean (Hard et al., 1968; Diebert et al., 1979).

According to Westermann et al, 1981, N fertilization in common beans depends on the variety, as well as on the N available from soil sources, the significant factor contributing to the lack of a response to N fertilization in the soils is the magnitude of the soil mineralized N during crop growth. Nitrogen fertilization might be required on soils with lower mineralizable N or initial soil nitrate (NO_3-N) levels.

2.2.1.3 Calcium (Ca)

Due to soil acidity in sub-Saharan Africa most of the soils have low Calcium content (Sylvie and Patrick, 2010). Calcium supplied to plants may perform multiple functions in plants as it is an essential component in nodule formation and symbiotic N_2-fixation in legumes. Studies have indicated that calcium deficiency in legumes depressed the calcium content of nodules, impairing nitrogen fixation due to inadequate calcium for nodule structure and metabolism. In this context, Ca^{2+} deficiency in legume decreased the supply of fixed nitrogen from nodules to other organs, thus negatively affecting plant growth (Banath et al., 1996).

2.2.2 Micronutrients

2.2.2.1 Zinc (Zn)

Zincis strait linked to synthesis of auxin and carbon metabolism, as well is important for water abortion in plant (Ded *et al*,, 2009; Coyne,2001) .Is important in production of biomass, fertilization and germination, and it is also the main component of enzyme system in the plant.Superoxide dismutase (SOD) has been considered the most important enzyme which catalyzes the disproportionate of the superoxide free radicals, formed in many biologic oxidations, and plays a vital role in protecting cells against deleterious effects of this radical (Fridovich, 1974). Is one of the micronutrients that limit productivity in common beans. Studies have shown that zinc increases yield and quality of common bean when zinc sulphate was supplied by foliar application at shooting, flowering and podding stages in comparable to soil application. Application of zinc sulphate had positive impact on formation of stamens and pollen, also increased the number of pods (Mahbobeh *et al.*, 2011).

2.2.2.2 Molybdenum (Mo)

Molybdenum is component of some bacterial nitrogenase and therefore is especially important for plants that live in symbiosis with N fixing bacteria; is considered as a component of two enzymes, both of which are important for nitrogen metabolism: nitrogenase, which is essential for N_2 fixing in the root system, and nitrate reductase, which is indispensable for the use of nitrates adsorbed by the common bean plant (Malavolta, 2006). It is generally accepted that legumes need more Mo than most of other plants due to its key involvement in the nitrogen -fixation process and important key role in chlorophyll synthesis (McBride, 2005). Studies have shown that bean seeds enriched with (Mo) increased nitrogenase activity at the vegetative stage, increase leaf area, and shoot biomass and N accumulation (Fernanda *et al.*, 2013).

Molybdenum deficient plants exhibit poor growth and low contents of chlorophyll and ascorbic acids and shows reduced leaf blade formation, inter-veinal mottling and chlorosis around edges and tips of older leaves (Sylvie and Patrick, 2010).

2.2.2.3 Boron (B)

Boron has an important role on maintenance of nodule cell wall structure (Matoh, 1997). Study on Pea (Pisum sativum L.), have shown that B fertilizer regulates water content in cells, reproduction and pollen formation also most of the cells are invaded by rhizobium under B fertilizer supplement (Milev, 2014).

Boron deficiency causes many anatomical, physiological, and biochemical changes, most of which represent secondary effects. Symbiotic events including rhizobial infection, nodule cell invasion and symbiosome development that involve membrane related functions are affected by B deficiency (Dale and Csryatyna, 1998). During B-deficiency nodules do not develop well, there is no proper cell proliferation and tissues are not properly differentiated to form nodules; structure like tumor (Miguel *et al.*, 2008).

2.2.2.4 Sulphur (S)

Sulphur and nitrogen roles are inter-related as their roles are related to synthesis of proteins (Arshad *et al.*, 2010).Such nutrients relationships have been established in studies in terms of their influence on dry matter and yield.Gooding and Davies (1997); reported that sulphur fertilizer in crop production has also an important role on formation methionine and cysteine amino acids which are responsible as building block of proteins. An increase on a percentage of N followed by yield increment of legume by S application has been reported especially in faba bean production (*Vicia faba* L.) (Scherer, 2001).

A shortage in the S supply to the crops lowers the utilization of the available soil nitrogen, thereby increasing nitrate leaching (O’Conner and Vartha, 1969).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Experimental Sites

The study was carried out at 2 different research sites, and different times of the year. The first experiment was conducted under rainfall conditions from December 2013 to March 2014 at Chitedze Agricultural Research Station, while the second one was planted at Kandiyani dam, near Chitedze Agricultural Research Station under irrigation from May, 2014 to August, 2014 (Table 3.1).

Table 3.1: Summary of characteristics of the trial sites

Description	Site 1 Chitedze	Site 2 Kandiyani
Longitude	$33^0$38'E	$33^0$23'E
Latitude	$13^0$59'S	$13^0$85'S
Altitude	1146 (masl)	1144 (masl)
Avg rainfall	892mm	892mm
Mean temp	24^0C	24^0C

Key: masl = meters above sea level

3.1.1 Rainfall

The total amount of rainfall during the 2013/ 2014 growing season (from December 2013 to April 2014) at Chitedze Research Station was 800mm where the peak was noted in the second decade of February. The crop experienced terminal drought where the rains stopped from second decade of February to second decade of March (Fig 1).

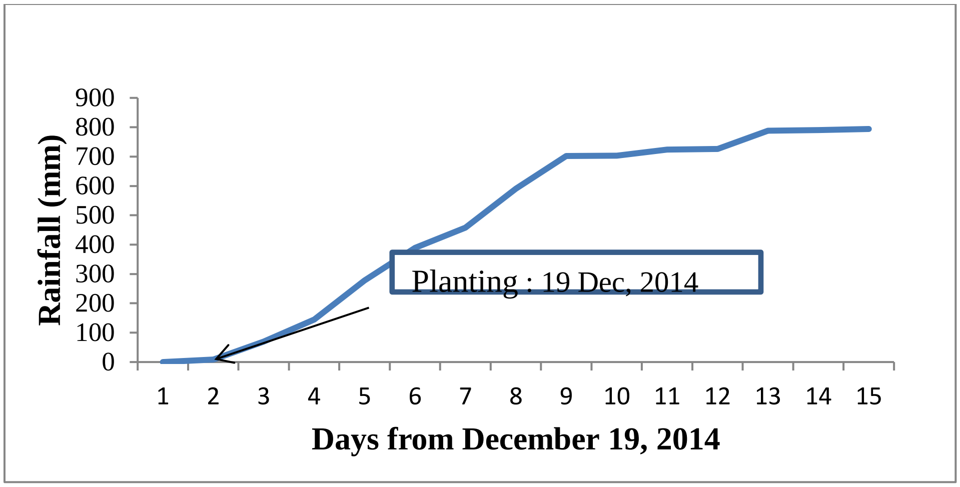

Figure 3.1. Cumulative daily rainfall, Chitedze Research Station, 2013-14

3.1.2 Temperature

The maximum average temperature of summer trials at Kandiyani dam was 27^0C from May to August 2014; July was the hottest month with 31^0C of temperature (Table 3.2).

Table 3.2: Temperature at Kandiyani for the irrigated common bean experiment

Month	Max(^{0}c)	Min (^{0}c)
May	26	13
June	25	10
July	31	10
August	27	12
Total average	27	11

3.2 Field management

Six main experiments were conducted: 2 under rain-fed conditions at Chitedze Research Station and four under irrigation at Kandiyani. These experiments were designed in split-plot treatment arrangement, laid out in a complete randomized block design with 3 replicates. In each replicate there were 9 main-plots representing the macro-nutrient, which were allocated at random and subsequently, each of the 4 micro-nutrient factors were also allocated at random to sub-plots within the main plots making a total of (9x4) 36 treatments in each replicate.

Each treatment plot size was 4 rows spaced at 0.75 m, and 5 m long. Each experiment had one bean variety – either bush bean (SUG131) or climbing bean variety (MAC53), and these were run concurrently. At the sites where there was irrigation the two experiments were done under two water regimes: a) with fulltime irrigation (no drought stress); and b) without irrigation after flowering to simulate terminal drought stress. As such there were 4 experiments at Kandiyani (2 bush bean trials – with and without drought stress and 2 climbing bean trials – with and without drought stress). At Chitedze however, it was not possible to have the drought stress during the rainy season, so there were only 2 experiments – 1 on bush and another on climbing bean variety.

3.3 Soil sampling

Soil samples were collected diagonally across the experimental field at 5 different points to get representative sample.

At each point, soil samples were collected at 3 different depths as follows; (0 -15 cm), (15-30 cm) and (30-45 cm). In total there were 15 soil samples for each research site as described in Figure 3.

The collected soil samples were analyzed at Lilongwe University of Agriculture and Natural Resources (LUANAR) and Extension Trust (ARET) laboratories for physical and chemical properties.

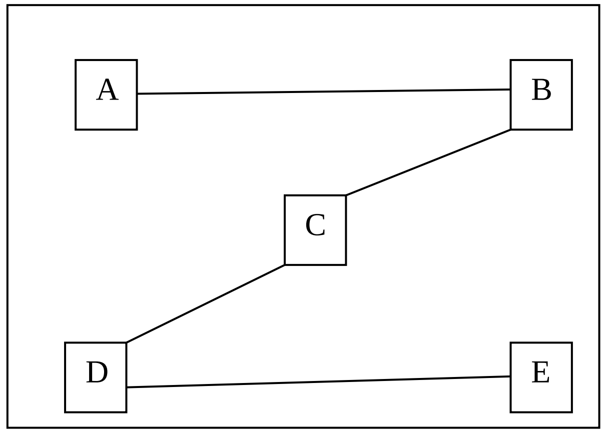

Figure 3.2 Schematic diagram to show the points (A, B, C, D and E) where soil samples were collected at 3 different depths.

3.4 Soil chemical analysis

3.4.1 Soil pH

The pH of the soil samples was determined from soil: water ratio of 1:2.5; which was constituted by mixing 10gwith 25 ml of distilled water in a centrifuge tube. The mixture was shaken for 10 minutes and thereafter allowed to settle for 30 minutes, then it was shaken again for 2 minutes after which pH was read on a pH meter (Anderson and Ingram, 1993)

3.4.2 Sulphate Sulphur

This was determined by using 5g of soil in centrifuge tube. Twenty five mls of potassium phosphate solution was added and put on a shaker for one hour. The mixture was centrifuged for 5 minutes and then filtered through a wet $SO^{-2}4$ free whatman No. 42 filter paper. Twenty mls of the clear extract was pipetted into boiling tubes. Standards were prepared from stock sulphate solution (K_2SO_4). Sulphate-sulfur was added to 0.5g of $BaCl_22H_2O$ crystal and then the result was read on spectrophotometer at 420nm wavelength (Johnson, 1992)

3.4.3 Phosphorus

Available phosphorus was determined by weighting 2.5g of soil sample, and then added 25 milliliters of Melich-3. The samples were shaken for five minutes. Thereafter were left overnight for setting, then filtration took place. One milliliter of the sample filtered was taken and 8 mls of working solution (Marphy-Rilley) was added thereafter samples were left for 30 minutes for color development. Thereafter were read on the spectrophotometer at wavelengths of 860nm to get absorbance (Anderson and Ingram, 1993).

3.4.4 Nitrogen

Total nitrogen was determined by weighing 200g of soil sample, and then was added 25 milliliters ofMelich-3.N1 and N2 solutions were then added for color development and nitrogen was read at 655nm. Nitrate-N was extracted using 2M KCl in a soil: ratio of 1:10 and putted on shaker for 30 minutes. This was left overnight to settle. Color was read at 210 nm wavelength (Anderson and Ingram, 1993).

3.4.5 Calcium, Potassium and Zinc

These three nutrient elements were extracted from the soil using Mehlich 3 solution. The soil extractants ratio was 1:10 and the sample was shaken for 5 minutes. Thereafter the samples were allowed to settle overnight and were them filtered through to 50 ml centrifuge tube. For Calcium and Potassium, 0.5 ml of the sample was pipetted into a glass vial into which 0.5 ml distilled water were added. These were diluted with 9 ml of 1000 ppm Strontium. The cations were determined with an Atomic Absorption Spectrophotometer (AAS) Model 200A at a wavelength of 422nm and 766.5 nm for calcium and potassium respectively. To determine zinc, the undiluted sample was read on the AAS (Anderson and Ingram, 1993).

3.5 Soil chemical characteristics at Chitedze Research Station and Kandiyani

3.5.1 Soil chemical characteristics at Chitedze Research Station

Among soil micro and macro nutrients done in this study it was however, not possible to analyze for same elements like molybdenum and sulfur because some apparatus were not working at campus soil laboratory. In addition, the analyses of calcium and zinc were done at ARET soil laboratory. The results for Table 6 is showing that soil texture ranged from sandy clay to clay loam, the soil was low fertile, slightly acidic, with average percentage of N, average available P and K and total Ca of 0.9%, 1.6ppm, .2.4cm/kg and 4.0 cm/kg respectively. The average micronutrients content was the same for Zn and B 0.3 pp. According to the critical soil test used by Snapp (1998), the soil fertility at Chitedze Research Station had low concentration of zinc .However, the concentration of calcium, phosphorus and potassium was found to be higher.

3.5.2 Soil chemical characteristics at Kandiyani dam

Soil texture at Kandiyani trial site was found to be sandy clay (Table 14). The soil was slightly acidic with 5.1 value of pH, with average percentage of N, average available P and K, total Ca of 0.3%, 1.5 Cm/kg, 2.6 Cm/kg and 5.9 Cm/kg respectively. The average micronutrients content ranged from 0.2 Zn pp to 0.4 B pp (Table 13). At Kandiyani dam, the soils where seen to be fertile with reasonable concentration of P, K and Ca elements but low concentration of Zn (Sapp, 1998).

Table 3. 3: Soil chemical properties at Chitedze Research station

Nutrient analysis	Depths			Means
	0-15	15-30	30-45	
pH	5 (0.3)	4.7(0.005)	5.1 (0.2)	4.7
N (%)	00.21 (0.1)	0.23 (0.03)	0.5 (0.08)	0.9
P (ppm)	1.69 (0.1)	1.69 (0.1)	1.39 (0.1)	1.6
K (cm/kg)	2.8 (4.45)	2.2 (0.3)	2.2 (0.5)	2.4
Ca (cm/kg)	2.75 (0.4)	4.3 (4.5)	3.5 (4.5)	4.0
Zn (ppm)	0.2 (0.08)	0.3 (0.05)	0.7 (0.04)	0.3
B (ppm)	0.33 (0.0)	0.54 (0.2	0.66 (0.3)	0.3
Class texture	SC to CL			

Key: * figures in brackets are standard deviation. N= Nitrogen, P= Phosphorus, K= Potassium, Ca=Calcium, B=Boron, Zn=Zinc, S.dep= sample depth, SC= sandy clay, CL= clay loam.

Table 3.4: Soil properties chemical characteristics at Kandiyani dam

	Well watered trial Depths (cm)		Mean	Stressed trial Depths (cm)		Mean
Nutrient analysis	0-15	15-30		0-15	15-30	
pH	5.5 (0.3)	5.5 (0.3)	5.4	5.3 (0.3)	5.1 (0.5)	5.2
N (%)	0.3 (0.02)	0.3 (0.03)	0.3	0.3 (0.08)	0.2 (0.1)	0.3
P (ppm)	1.4 (0.1)	1.5 (0.3)	1.5	1.5 (0.3)	1.4 (0.1)	1.5
K (cm/kg)	0.5 (0.4)	3.6 (0.1)	2.6	2.7 (1.3)	1.8 (0.7)	2.3
Ca (cm/kg)	3.7 (0.7)	4.6 (0.8)	4.2	5.3 (1.5)	4.5 (1.2)	5.9
Zn (ppm)	0.3 (0.04)	0.3 (0.05)	0.3	0.3 (0.04)	0.2 (0.1)	0.2
B (ppm)	0.3 (0.01)	0..4 (0.05)	0.3	0.3 (0.1)	0.5 (0.1)	0.4
Texture Class	SC	SC			SC	SC

Key: * figures in brackets are standard deviation. N= Nitrogen, P= Phosphorus, K= Potassium, Ca=Calcium, B=Boron, Zn=Zinc, S.depth= sample dept, SC= Sandy clay

3.6 Field Operations

3.6.1 Fertilizer application

The experiment had 9 macro-nutrient (9 levels)which included: 1) zero – no macro-nutrient (control); 2) Nitrogen (N); 3) Phosphorus (P); 4) Potassium (K); 5) Calcium (Ca); 6) N2-fixation –CIAT 899 Rhizobium (Rz); 7) Nitrogen combined with Phosphorus(NP); 8) Phosphorus combined with rhizobium (PRz); and 9) A combination of NPK fertilizers. Under each one of the macro-nutrients there were 4 micro-nutrients (4 levels): 1) Boron (B); 2) molybdenum (Mo); 3) Zinc (Zn); and 4) Sulfur (S). There were 36 treatments as follows: 1- N+ZnS; 2- NPK+ZnS; 3- K+ZnS; 4- Ca+ZnS; 5- Rz+ZnS; 6- NP+ZnS; 7- NPK+ZnS; 8- NPRz+ZnS; 9- ZnS; 10- N+Mo; 11- NPK+Mo; 12- K+Mo; 13- Ca+Mo; 14- Rz+Mo; 15- NP+Mo; 16- NPK+Mo; 17- NPRz+Mo; 18- Mo; 19-N+ B; 20- NPK+B; 21- K+B; 22- Ca+B; 23- Rz+B; 24- NP+B; 25- NPK+B; 26- NPRz+B; 27- B; 28-N; 29- P; 30- K; 31- Ca; 32- Rz; 33- NP; 34- NPK; 35- NPRz; 36- Control.

Before planting, the field was irrigated to field capacity, and the following day fertilizer application was done. The fertilizer was applied by plot as each treatment had its own fertilizer type and rate of application

3.6.1.1 Sodium molybdate

For sodium molybdate, seed treatment was done following the literature [The Fertilizer Society of South Africa (FSSA), 2007] that recommend 100g of molybdenum which correspond to 250g of sodium molybdate to treat 100kg of groundnut or bean seed. As such, the quantity of sodium molybdate to treat the common bean seed for each experiment was calculated based on the above recommendations. For the treatments that had rhizobium plus sodium molybdate, the sodium molybdate was applied immediately after seed inoculation with rhizobium.

3.6.1.2 Calcium Oxide (CaO_2)

Foliar application was made days after emergence at first three nodes on the main stem with trifoliate leaves V_3 (Sergio *et al*., 2002). According to fertilizer supplier, 20 litres of extra-cal can be sprayed on 1ha of common beans crop. The fertilizer ratewas calibrated using a proportion of 1:2 which means 1 litre of extra-cal was added to 2 litres of water.

3.6.1.3 Seed inoculation (Rhizobium application)

One sachet of 50g of inoculant was mixed in 200mls of water, in which 1 level match box of sugar was added. Required quantity of seed was added into inoculant mixture (water, sugar and inoculant) per variety (Climb and bush) separately and mixed thoroughly until the seed was moist and well coated with inoculant. All the seed was removed from the inoculant mixture and spread on clean sack and kept in the shade to dry away from direct sunlight. The seed was planted within 48 hours.

Table 3.5: Source and concentration of nutrients applied

Source	Nutrient	Content of nutrients Concentration in (%)	Nutrient level (kg ha^{-1})
Urea $CO(NH_2)_2$	N	46	46
Omnisupers (P_2O_5)	P	24	11.22
Muriate of potash (KCL)	K	60	50
Calcium extra cal (CaO_2)	Ca	18.2	0.3
Zinc sulphate ($ZnSO_4$)	Zn and S	36 and 9.9	7.1 and 1.8
sodium molybdate ($Na_2MoO_4.2H_2O$)	Mo	39.7	1
Solubor	B	20.5	1

3.6.1.4 Irrigation and soil moisture measurement

Irrigation was done using an over head sprinkler. Soil moisture meters were used to measure moisture in the soil. Six watermark sensors were installed at three different sites in each replication at 0-5 cm, 5-10 cm, 10-20 cm, 20-40 cm, 40-60 cm and 60-80 cm soil depths. Soil water tension readings were recorded every day from planting to harvesting at 09:00hrs.

3.6.1.5 Weed and pest control

Weed control was done by weeding using a hand hoe when necessary. The insecticide Dimethoate 400 EC (systemic and contact insecticide) was applied on foliar canopy at a rate of 1ml per one (1) litre of water using a knapsack sprayer to control aphids and trips.

In addition Karate was also applied using hand sprayer from onset of flowering until pod maturity to control flower and pod boring insects, both insecticide were applied weekly.

3.7 Data collection

Soil physical and chemical data were collected at each site as described in the section under materials and methods. Crop phenological data were collected during the crop growth period and these included: stand count after emergence and days to flowering.

Destructive sampling to observe nodule evaluation at 6 weeks after planting was done on5 plants sampled at 0.5m on the 2 outer rows. On the same day, the nodules were counted and all nodules were removed from the root and weighted.

3.7.1 Quantum Yield (QY)

This is a measurement of formation of gases such as O_2or CO_2which depends on temperature, CO_2 and O_2 uptake, James and Olle, (1977). This parameter was measured by a non destructive hand- held QY meter. This was done by selecting younger and fully expanded leaves (YFEL) from a plant plot. Usually this leaf is among the second and third or fourth set of leaves from the youngest on top of the plant. The readings were made at mid pod filling growth stage, around 09:00 to 11:00 in the morning according to the recommendation in the manual.

3.7.2 Leaf chlorophyll content

Leaf chlorophyll was measured using chlorophyll meter (CCM-200, Opti- Science, USA). For this parameter, non destructive sampling was done by taking measurements from young and well expanded leaves three times from each plot and the mean of chlorophyll content per leaf was recorded.

3.7.3 Yield components and yield determination

Plants in the net plot were harvested for yield determination. All harvested pods were weighed and left for 3 days in the sun to dry. After shelling the weight of the grain was measured per treatment.

3.7.4 Dry matter (DM) and harvest index (HI) determination

This was done by separation of shoots into leaves, stems and pods at mid pod crop stage, and then fresh weight were taken. All separated parts were put in separate paper bags and oven dried at 60^0c for 48 hours in the oven and dry weight was taken. The recorded value was used to determine total dry matter production and dry matter distribution in different plant parts (leaf biomass, steam biomass and pod biomass)

DM% = Dw (leaves, stems, pods) / FW (leaves, steams, pods) × 100

Where:

DM= dry matter; DW= dry weight of leaves, stems and pods; FW= fresh weight of leaves, stems and pods.

Harvest index (%) was calculated using the following equation:

$$HI= \frac{SY}{BY} X100$$

Where: HI: Harvest index

SY: Seed Yield

BY: Biological Yield (excluding roots and fallen leaves), from Efraín et al. (2009).

3.7.5Drought susceptibility index (DSI), drought intensity index (DII) and drought tolerance efficiency (DTE)

The DSI and DII were calculated using the Fisher and Maurer Index (1978) as:

DSI = (1-Yds/Yns) / DII

Where:

Yds and Yns are mean yield of two given varieties in drought stress (ds) and no stress (ns) treatments respectively and DII is the drought intensity index

DII = 1-Xds / Xns

Where:

Xds and Xns are the average seed yield of all varieties under drought stress (ds) and no stress (ns) treatment respectively.

Drought tolerance efficiency (DTE) was estimated by using formula given by Fischer and Wood (1981) as:

DTE% = $\frac{Yieldunderstress}{Yieldunderno-stress} x\ 10$

3.8 Data analysis

3.8.1 Mathematical model

Grain yield and other data were analyzed using General statistics (Genstat 16^{th} Edition) computer package. General analysis of variance for split plot arrangement was used for each of the 6 trials separately to test the source of variance and interaction between macro and micro-nutrients on yield and yield components. The statistical model used is described below:

$Y_{ijk} = \mu + S_i + MA_j + ML_{k(i)} + (MA + ML)_{jki} + \varepsilon_{ijk}$

Where:

Y_{ijk} = responses

μ = overall mean

S_i = random effect of i^{th} site

MA_j = fixed effect of j^{th} macronutrients

$ML_{k(i)}$ = fixed effect of k^{th} micronutrient nested within block

ε_{ijk} = random error

Furthermore combined analysis of variance (ANOVA) for split-split-plot arrangement Across 2 water regime was used for both beans type: bush bean (drought x non drought), climber (drought x non-drought), the statistical model used is described below:

$Yijk = \mu + S_i + W_i + MA_j + MI_k + W_i (MA)_j + W_i (MI)_k + MA_j(MI)_k + W_iMA_jMI_k +$ error $(block/W_i/MA_j)$

Where:

Yijk= Response

μ= overall mean

S_i = random effect of i^{th} site

W_i=effect of i^{th} water regime

MA_j = effect of j^{th} macronutrients

MI_k = effect of k^{th} micronutrient

$W_i\ (MA)_J$ = the effect of interaction between the i^{th} water regime and the j^{th} macronutrients

$W_i\ (MI)_k$= the effect of interaction between the i^{th} water regime and the k^{th} micronutrient

$MA_j\ (MI)_k$ = the effect of interaction between the j^{th} macronutrients and the k^{th} micronutrient

$W_iMA_jMI_k$ = the effect of interaction between i^{th} water regime, j^{th} macronutrients and k^{th} micronutrient

$\mathcal{E}_{ijk}$ = random error

3.9 Correlation coefficient (r)

To determine the strength of the relationship between all measured variables, correlation coefficient was used. The analysis was also done using Genstat (16^{th} edition).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Rainfed experiments at Chitedze Research Station

4.1.2Effect of macronutrients and micronutrients on yield and yield components on bush bean under rainfed conditions

Micronutrient (Mic) application had significant effects on days to flowering ($P < 0.05$) and chlorophyll content in the leaves ($P < 0.01$) (Tables 4.1 and 4.4). However, macronutrient and micronutrient combination (Mac x Mic) had significant effects on days to flowering and seed yield per hectare ($P < 0.05$) (Tables 4.1 and 4.5), while the number of nodule per plant and fresh weight of nodules were significantly different at $P < 0.01$ level (Tables 4.2 and 4.3).

There was significant interaction between macronutrients and micronutrients on days to flowering (Table 4.1). For most treatments, the flowering occurred 40 to 46 days after planting (DAP), while treatments with seed treated with molybdenum only and treatments with N fertilizer only the flowering occurred 35 DAP. Few days to flowering (30 days) was noted on NP+Mo treatments application (Table 4.1).These results agree with research done by Fernanda et al. (2013), where prior seed treatment with high levels of molybdenum resulted in early flowering as compared to non treated seeds. This may suggest that molybdenum application is vital in reproduction as it has an influence flowering.

Macronutrients (Mac) application showed significance differences at $P < 0.05$ on fresh weight of nodules and the combination of micro and macro-nutrient fertilizer (Mac x Mic) had significant effects on both number of nodules per plant and fresh weight of nodules at

$P < 0.01$ level (Tables 4.2 and 4.3). High mean was found on treatments with seed coated with molybdenum and added NPK fertilizer, followed by treatments with seed treated with rhizobium and applied NP fertilizer (Table 4.2).

The increase can be related to P fertilizers role on nodulation, nodule growth and chemical activity or function in legumes (Miao et al.; 2007). These results are comparable with (Moharram et al.; 1994), where inoculated soyabean and applied P fertilizer increased nodule formation, nodule number and nodule weight 60 days after planting. Saadallah et al. (2001) and Vadez and Devron (2001), also reported that active uptake of P by bean plants result in a higher nodule formation and a higher nodule biomass.

The results revealed significant differences on chlorophyll content by micronutrient application ($P < 0.01$), and macro nutrient ($P < 0.05$) application, separately (Table 4.4). However, macro- micronutrient interaction (Mac x Mic) had no effect on chlorophyll content on the leaves. Chlorophyll content on the leaves was high on Mo treatments followed by N treatments (Table 4.4).Results showed that chlorophyll content increased on the leaves by Mo fertilizer supplement. This must be because of the role of molybdenum in synthesis of nitrogenase and chlorophyll which causes an increase in chlorophyll content in the leaves (Biscaro et al., 2009; Bambara and Ndakidemi, 2010; Westermann (2005) also reported that Mo is essential for nitrate reductase and nitrogenase enzyme activity making it an essential component in chlorophyll formation. Furthermore, studies have shown a reduction in chlorophyll content on the leaves by Mo fertilizer omission on rice and soyabean crops (Moraes et al., 2009; Gupta et al., 1991).Similar results related to chlorophyll increases caused by N fertilizer application on chickpea were also reported by

(Ali et al., 2013), where nitrogen fertilizer significantly affected chlorophyll content and leaf area index (LAI). This can be explained by the role of nitrogen in the plant which influences the amount of protein, protoplasm and chlorophyll formation, and also influence cell size, leaf area and photosynthetic activities (Caliskan et al., 2008).

Application of macro-nutrients and the interaction of macro-micro nutrients significantly affected seed yield at P<0, 05 (Table 4.5).Although the yield did not vary much among the treatments, the highest yield (1900kg/ha) was observed on NPRz + Mo treatments followed by seed treated with rhizobium plus NP fertilizer. These results show that treatments where seed was inoculated with Rhizobia and P fertilizer was present resulted in high yield (Table 4.5).Despite no positive response on rhizobium application alone, Amos et al. (2001) reported significant increase on seed yield where P and rhizobium were applied together. This may suggest a positive interaction between P and rhizobium yield and yield components of beans. Colonization of rhizobium increases nitrogen fixation which stimulates plant growth and development in legumes. As a source of nitrogen, it is important in enzymatic processes in plants and is part and parcel of chlorophyll formation (Uchida, 2000). On the other hand, phosphorous plays an important role in photosynthesis and chlorophyll formation. It is also hugely important in energy transfer as it is part of the energy chemical molecules adenosine triphosphate (ATP) and adenosine diphosphate (ADP) (Montanaro et al., 2005). In view of this, the roles of phosphorous and rhizobium on plant growth and development explains why there was significantly higher yield than in the other treatments. In addition, the higher requirements for phosphorous by legume plants also explains the higher yield in treatments where P was applied (Shahid et al., 2009).

The results also showed that increase in common beans seed yield per hectare can be achieved when seed inoculated with rhizobium and applied with more than one macronutrient were added. This can be observed where nitrogen, phosphorous, Rhizobium and molybdenum (NPRz x Mo) and also where seed treated with rhizobium were applied with N and P fertilizer only (Table 10). Similarly, Rasool et al., 2006, reported that a combination of seed treated with rhizobium and NP application resulted in significantly higher yields in mungbean than other treatments where rhizobium, Nitrogen and phosphorous were applied separately.

Table 4.1: Macronutrients and micronutrients effect on days to flowering

Fertilizer	ZnS	Mo	B	Control	Mean
N	47	30	42	35	39^{a}
P	45	46	46	45	46^{b}
K	46	46	46	46	46^{b}
Ca	40	41	47	46	44^{b}
Rz	46	45	46	45	46^{b}
NP	42	44	43	40	$42a^{b}$
NPK	45	40	43	46	44^{b}

NPRz	45	46	44	40	44[b]
Control	46	35	45	47	43a[b]
Mean	45[ab]	41[a]	45[ab]	43[ab]	44

	P values	SE	LSD
Mac	ns	1.214	3.64
Mic	0.04	0.914	2.591
Mac x Mic	0.03	2.667	7.522
CV(%) 10.5			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.2: Macronutrients and micronutrients effect on number of nodules

Fertilizer	ZnS	Mo	B	Control	Mean
N	50	39	64	105	65b[cd]
P	119	174	123	122	135[ab]
K	97	147	77	59	95ab[cd]
Ca	81	102	39	43	66[bcd]
Rz	145	199	145	102	148[a]
NP	38	71	60	42	53[cd]
NPK	57	204	99	136	124[abc]
NPRz	143	169	113	191	154[a]
Control	76	43	36	40	49[d]
Mean	90a[b]	128[a]	84[ab]	93[ab]	99

	P values	SE	LSD
Mac	ns	24.36	73.02
Mic	ns	12.62	35.78
Mac x Mic	<0.01	40.84	115.38
CV% 66			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.3: Macronutrients and micronutrients effect on fresh weight of nodules

Fertilizer	ZnS	Mo	B	Control	Mean
N	0.4	0.1	0.4	0.4	0.3[b]
P	0.8	1.7	0.5	0.6	0.9[a]
K	0.7	0.4	0.6	0.5	0.5[ab]
Ca	0.5	0.5	0.3	0.7	0.5[ab]
Rz	0.6	0.9	0.5	0.5	0.7[ab]
NP	0.3	0.4	0.4	0.3	0.4[ab]
NPK	0.5	1.5	0.4	0.8	0.8[ab]
NPRz	0.6	0.8	0.5	1.3	0.8[ab]
Control	0.5	0.2	0.3	0.2	0.3[b]

Mean	0.6^a	0.7^a	0.5^a	0.6^a	1.0

		P values	SE	LSD
	Mac	0.02	0.1	0.5
	Mic	ns	0.1	0.3
	Mac x Mic	<0.01	0.3	0.8
	CV% 79.0			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.4: Macronutrients and micronutrients effect on chlorophyll content on the leaves

Fertilizer	ZnS	Mo	B	Control	Mean
N	20	47	30	40	34^a
P	31	31	31	31	31^a
K	32	31	31	31	31^a
Ca	32	31	31	31	31^a
Rz	31	31	34	38	34^a
NP	32	32	32	32	32^a
NPK	30	29	31	30	30^a
NPRz	29	35	29	31	31^a
Control	31	55	32	32	38^a
Mean	30^a	36^a	31^a	33^a	32

		P values	SE	LSD
	Mac	ns	1.342	4.024
	Mic	<0.01	0.6	1.7
	Mac x Mic	ns	2.056	5.823
	CV% 10.0			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.5: Macronutrients and micronutrients effect on seed yield (Kg/ha)

Fertilizer	ZnS	Mo	B	Control	Mean
N	843	535	825	645	712^{ab}
P	669	618	539	700	632^b
K	536	790	725	709	690^{ab}
Ca	563	790	725	525	651^b
Rz	772	830	852	724	795^{ab}
NP	870	790	725	695	770^{ab}
NPK	839	744	688	785	764^{ab}
NPRz	858	1900	865	950	1143^a
Control	570	661	675	544	613^b

Mean	724ab	851a	735ab	697ab	752

	P values	SE	LSD
Mac	0.05	52.3	209
Mic	ns	2.7	85.7
Mac x Mic	0.05	78.7	297.5
CV% 21.3			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

4.1.2.1 Correlations among traits of bush bean under rain fed at Chitedze research station.

Results showed most traits and yield components were positively and strongly correlated with grain yield (Table 4.6).Stand count, days to flowering, number of pods, leaf dry matter and stem dry matter were strongly correlated with grain yield. Although there was a positive correlation between number of nodules and grain yield, the correlation factor was not as strong as in other traits (emergence count, days to flowering, chlorophyll, number of pods among others) (Table 4.6).The yield of common beans has been related to a number of traits, such as branching and branch number, leaf growth and leaf area which facilitates assimilates production by the canopy crop in development. The traits are also related with photosynthate translocation to economic organs (Marie-Helene and Bertrand.; 1997).This may also be as a result of the influence of Rhizobium, macronutrients and micronutrients or their interactions on plant growth and development and they have an effect on chlorophyll formation, photosynthesis, energy transfer and enzymatic reactions among others (Uchida, 2000; Montanaro et al. 2005).These correlation results are similar to what (Sofi1 et al.; 2011; Haluk and Vahdettin, 2013) reported.

Table 4.6: Correlation coefficient among grain yield and yield components of bush bean under rain fed conditions.

	EC	NN	NW	DF	CHL	QY	NP	LDM	SDM	PDM	YD
EC	1										
NN	-0.03	1									
NW	0.07	0.74***	1								
DF	0.51***	0.04	0.02	1							
CHL	0.49***	0.02	0.06	0.81***	1						
QY	-0.03	-0.05	-0.06	0.04	-0.02	1					
NP	0.05	-0.01	-0.08	0.29***	0.2	0.20***	1				
LDM	0.18**	-0.13*	-0.28***	0.24***	0.23***	0.23***	0.19**	1			
SDM	-0.16**	0.07	-0.04	0.19**	0.08	0.08	0.63***	0.15**	1		
PDM	0.12*	-0.12*	-0.09	0.08	0.09	0.09	-0.06	0.3	-0.09	1	
YD	0.33***	0.11*	0.05	0.33***	0.29***	0.29***	0.28***	0.29***	0.30***	0.06	1

Key: EC= emergence count, NN= number of nodules, DF= days to flowering, CHL= chlorophyll content, QY= quantum yield, NP= number of pods, LDM= leave dry matter at mid pod filling stage, SDM= steam dry matter at mid pod filling stage, PDM= pod dry matter at mid pod filling stage, YD=grain yield, *P≤0.05, **P≤0.01, ***P≤0,001

4.1.3Effect of macronutrients and micronutrients on yield components and grain yield on climber beans under rainfed

Results showed significant responses on nodule number, nodule weight, pod number and grain yield per hectare. Those parameters were affected by some of the fertilizer application, the effects were observed when macronutrient (Mac), and Mac x Mic combination were applied (Tables 4.7, 4.8, 4.9 and 4.10).

Greater mean performance on number of nodules per plants and nodules fresh weight were found on those treatments with seed inoculated with Rhizobium and applied NP fertilizer in presence of molybdenum (Table 4.7). Nodule weight mean was greater than overall mean of NPRz + Mo fertilizer and this also was significantly different and compared to those treatments supplied with NPK plus other micronutrients (Table 4.8). Phosphorus fertilizer had positive effect on nodule fresh weight which was higher than NPRz +Mo treatments (Table 4.8).Researches on common beans have shown, an increase in nodule number and nodule weight of common beans inoculated with rhizobium and NP application improves seed yield. Similar studies by Kremer and Peterson, 1983; Kannaiyan, 2002 revealed that application of rhizobium, nitrogen and phosphorous results in increased nodule numbers, nodule weight and subsequently grain yield.

Role and importance of macronutrients N and P and micronutrient molybdenum (Mo) on common beans production is shown in Table 4.7, where higher values on number of pods are found almost in all traits which were significantly higher when NP and Mo fertilizers were applied. Micronutrients (Mic) application significantly affected the number of pods per plant ($P<0.05$), while Mac x Mic interaction was highly significant for number of pods per plant ($P <0. 001$) and significant for grain yield per hectare ($P<0.05$).

Almost all treatments where molybdenum was applied had higher number of pods than those without molybdenum (Table 4.9).

An experiment on yield increment with N and Mo application was reported by Brkić et al. (2004), who inoculated pea seed and applied N and Mo, molybdenum fertilizer increased yield and yield components compared to the treatments without molybdenum fertilizer application. The role of molybdenum in nitrogenase synthesis in rhizobium symbiosis in legume plants explains why there are significantly higher yields and yield components where Mo is involved (Biscaro et al., 2009).

Higher number of pods (185 pods per plants) was recorded on those treatments with NPK in presence of molybdenum fertilizer. On the other hand, low number of pods was observed on those plants with single macronutrients: Ca with 61 pods per plants; P with a mean of 74 pods per plant; rhizobium and NPK with means of 85 and 97 pods per plant respectively (Table 4.9). Among all groups of macro and micronutrients applied on climber beans under rainfed trial, NP fertilizer in presence of molybdenum had responded satisfactorily on seed yield per hectare with 1700 kg/ha against 377 kg/ha found on those beans where calcium was applied.

The result found in this experiment on increment of number of pods per plant by Mo application combined with NPK, are corroborated with those results by (Kandil et al., 2013) which were obtained by applying phosphorus and molybdenum which was reported to produce significantly higher yields and yield components on common beans. The research reported higher number of pods when Mo fertilizer was applied in presence of phosphorus alone. Phosphorus has also been reported to enhance number and fresh weight of nodules by its involvement on energy transfer that takes place in the nodule. There was observed increase in photosynthetic efficiency in the plants in the presence of P fertilizer and rhizobium which resulted in increased of number pods per plant and consequently produced a greater total yield of pea (Omar et al., 1990). In addition, phosphorus application is also reported to significantly promote formation of nodules and pods in legume plants (Buttery, 1969).

Table 4.7: Macronutrients and micronutrients effect on nodule number

Fertilizer	ZnS	Mo	B	Control	Mean
N	93	103	253	73	131[abc]
P	47	253	38	158	124[abc]
K	143	143	117	82	121[bc]
Ca	36	58	18	49	40[c]
Rz	167	246	167	153	183[abc]
NP	186	441	232	167	257[ab]
NPK	77	246	92	30	111[bc]
NPRz	203	440	187	305	284[a]
Control	55	59	57	50	55[c]
Mean	112[b]	221[a]	129[b]	119[c]	145

	P values	SE	LSD
Mac	0.07	75.8	160.6
Mic	ns	29.7	59.6
Mac x Mic	0.02	108.2	217.3
CV% 75			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.8: Macronutrients and micronutrients effect on fresh weight of nodules

Fertilizer	ZnS	Mo	B	Control	Mean
N	0.5	1.1	1.4	0.4	0.83^{c}
P	0.4	1.6	0.6	2.7	1.7^{abc}
K	1.2	1	0.8	0.6	0.87^{bc}
Ca	0.2	0.7	0.5	0.6	0.51^{c}
Rz	1.3	2	0.6	1.3	1.26^{abc}
NP	1.1	4	2.4	1.3	2.26^{a}
NPK	0.86	1.1	0.7	0.3	0.77^{c}
NPRz	1.5	3.2	1.6	2.1	2.2^{a}
Control	0.3	0.5	0.4	0.5	0.42^{c}
Mean	0.84^{c}	2.0^{a}	1.43^{ab}	1.24^{ab}	1

	P values	SE	LSD
Mac	0.09	0.64	1.36
Mic	ns	0.24	0.48
Mac x Mic	0.05	0.89	1.8
CV% 76.9			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different

Table 4.9: Macronutrient and micronutrients effect on number of pods

Fertilizer	ZnS	Mo	B	Control	Mean
N	116	151	143	126	134^{a}
P	75	126	121	74	99^{b}
K	116	149	146	132	136^{a}
Ca	97	94	60	61	78^{b}
Rz	126	162	100	85	118^{ab}
NP	124	132	132	107	124^{ab}
NPK	145	184	113	97	135^{a}
NPRz	110	142	108	114	119^{ab}
Control	145	110	110	103	117^{ab}
Mean	117ab	139^{a}	115^{ab}	100^{ab}	118

	P values	SE	LSD
Mac	ns	22.35	47.38
Mic	0.06	7.65	15.33
Mac x Mic	<0.001	29.9	60.3
CV% 23.7			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different

Table 4.10: Macronutrient and micronutrients effects on grain yield (Kg/ha)

Fertilizer	ZnS	Mo	B	Control	Mean
N	842	1002	832	770	862^{b}
P	735	772	842	568	729^{abc}
K	700	881	698	591	718^{abc}
Ca	520	450	408	377	439^{c}
Rz	832	718	724	876	788^{abc}
NP	794	1700	694	612	950^{a}
NPK	121	649	965	698	608^{abc}
NPRz	669	1000	684	641	749^{abc}
Control	602	981	552	721	714^{abc}
Mean	646^{ab}	906^{a}	711^{ab}	650^{ab}	728

	P values	SE	LSD
Mac	ns	173.3	367.5
Mic	ns	66.4	133.2
Mac x Mic	0.04	244.6	491.5
CV% 33.8			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

4.1.3.1Correlations among traits of climber bean under rain fed at Chitedze Research Station.

Correlation analysis revealed a significantly strongly positive correlation between number of pods and grain yield. However correlation was not strong between other parameters such as chlorophyll and leaves dry matter. However, a significantly negative correlation between nodule weight, leaf dry matter and grain yield was found (Table 4.11).

This negative correlation result may be because of the varieties used since some varieties are more efficient in using photo-assimilates into producing grain. On the contrary, Stockerman et al., 1995, revealed a positive correlation between nodule weight, nodule numbers and grain yield. It was reported that root nodules serve as sites for molecular reduction and symbiotic exchange and this is directly related to yield as this has an influence on morphogenetic nod factors (Table 4.11).

These results on correlation between number of pods per plant and grain yield are similar to those reported by Haluk and Vahdettin (2013) and Fargeri et al (2010) on bush beans research, in which a positive correlation was reported. By this positive correlation, Bennet et al., 1977 further recommended that number of pods per plant should be one of the parameters as selection criterion to increase common bean yield.

Table 4.11: Correlation coefficient among grain yield and yield components of climber bean type at Chitedze Research Station under rainfed conditions.

	EC	NN	NW	DF	CHL	QY	NP	LDM	SDM	PDM	YD
EC	1										
NN	0.40***	1									
NW	0.32***	0.79***	1								
DF	-0.23***	-0.15**	-0.13*	1							
CHL	-0.21***	-0.26***	-0.23**	-0.04	1						
QY	0.004	0.002	-0.004	0.14*	-0.13*	1					
NP	0.33***	0.08	-0.05	0.2	-0.15**	0.09	1				
LDM	-0.06	-0.07	-0.08	0.11*	0.13*	0.11*	0.27***	1			
SDM	0.18**	0.03	0.11*	-0.1	0.13*	-0.07	-0.57***	-0.25***	1		
PDM	0.03	-0.0007	-0.06	0.02	-0.21**	-0.11*	0.24**	0.10*	-0.22**	1	
YD	-0.04	-0.009	-0.12*	0.02	0.13*	0.16**	0.39***	0.22**	-0.38***	-0.02	1

Key: EC= emergence count, NN= number of nodules, NN= weight of nodules, DF= days to flowering, CHL= chlorophyll content, QY= quantum yield, NP= Number of pods per plant, LDM= leaf dry matter at mid pod filling stage, SDM= steam dry matter at mid pod filling stage, PDM= pod dry matter at mid pod filling stage, YD= grain yield, *P≤0.05, **P≤0.01, ***P≤0,001

4.2Irrigated experiments at Kandiyani

4.2.1Effect of macronutrients and micronutrients on yield components and grain yield on bush beans under well -watered conditions

The results of analysis of variance (ANOVA) for split plot treatment on bush beans under non-stressed trial showed significant differences amongst macronutrients (Mac) application on chlorophyll content on the leaves, number of nodules per plant and fresh weight of nodules, percentage of dry matter on the (leaves, stems and pods) at $P < 0.05$ level and seed yield ($P < 0.01$) per hectare (Tables 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18). The interaction between macronutrients and micronutrients (Mac x Mic) showed significant effects on nodule number at $P < 0.001$, nodule weight and seed yield per hectare at $P < 0.01$ levels (Tables 4.13, 4.14 and 4.18). However, micronutrient application did not show any significant differences among parameters on yield and yield components on bush beans on the fully irrigated trial.

Number of nodules per plant and fresh weight of nodules were seen to be affected by macronutrient (Mac) and combination of macro and micronutrient (Mac x Mic) (Table 4.13 and 4.14). Mac x Mic combination had strong effect on increased number and fresh weight of nodules, treatments with combined P and Mo application significantly gave higher number and nodule weight (Table 4.14). Among all the treatments with macronutrients with any micronutrient combination, higher number of nodules was observed on P fertilizer application. Nitrogen and Ca treatments had lower number of nodules (8 per plant) than control (38 per plant) (Table4.13).

According to Mfilinge *et.al.,(*2014) phosphorus is needed in relatively large amounts than other macronutrients by legumes for crop growth and development, which positively promote legumes growth and yield, nodule number and nodule weight in different legumes. Elkoca *et. al.*, (2007) also reported that high P fertilizer application is very important on nodule formation in legumes. In addition, (Zahran, 1999) also confirmed that nodulated legumes require high level of P fertilizer for optimal performance. These results confirm the importance of P fertilizers on nodule formation.

This study found that nitrogen fertilizers resulted in lower number of root nodules. This is corroborated with (Otieno *et al.*, 2009) who reported a reduction in root nodule numbers and nodule weight in different legumes such as Common beans (*Phaseolus vulgaris* L.), lima beans (*Phaseolus lunatus* L.), green gram (*Vigna radiata* L.) and lablab (*Lablab purpureous* L.) as compared with control, and Rhizobia inoculant treatments. In addition, (Roberta *et al.,* 1994) also reported a reduction in nodule number and nodule weight in mung bean (*Vigna radiata (L.)* Wilczek) where ammonium –N fertilizer was applied. Importantly, Abdul, (2007) revealed that nitrogen rates are very important in nodule formation as nodulation in pea was diminishing with increasing rates. These results are similar to those reported by Oroka (2010) which revealed reduced number of nodules and nodule weight by increasing the amount of nitrogen fertilizer application. Abdel and abd-Alla (1996) reported that the amount of nitrogen is very crucial in root nodulation as this affect nitrogenase and nitrate reductase activities which consequently reduced number of nodules and nitrogen fixation. The nitrogen fertilizer rate of application in this study, may explain the reduction in the root nodules.

Chlorophyll content in the leaves was affected by macronutrient (Mac) application. Results in this study showed an increment in chlorophyll content in the leaves when NPK macronutrients were applied. However, the amount of chlorophyll content in the leaves did not differ much among the (N, P, K, Ca, Rz, NP, and NPRz) treatments. But higher chlorophyll content in the leaves was observed where NPK fertilizer was applied and recorded 58% chlorophyll in their leaves unlike treatments where Ca fertilizers was applied which recorded 35% chlorophyll content (Table4.12).

Chlorophyll content increment influenced by NPK fertilizer application in the leaves could be explained by better uptake of nitrogen by common beans plants. This is in agreement with Uzoma *et al*. (2013) that the greatest and lowest leaf chlorophyll was associated with N treatments and non-N treatments, respectively. In addition positive correlation between nitrogen fertilizer and chlorophyll content in the leaves of rice has been reported, mainly either due to the presence of nitrogen in the structure of chlorophyll molecules or due to nitrogen fixation which increases nitrogen content of vegetative tissues (Qrbanly et al., 2006).

The dry matter in the leaves, stems and pods was significantly affected by macronutrient (Mac) application. Significantly higher dry matter (Dm) in leaves and stems was observed where K fertilizer was applied unlike other treatments (Tables 4.15 and 4.16). However, a significantly high dry matter (Dm) of pods was observed in plants whose seed was inoculated with rhizobium unlike the other fertilizer treatments.

Results found on increment of leaves and stems dry matter by K fertilizer application on common beans is in tandem with those found by Zarenia *et al*. (2013), where K fertilizer application was highly significant at P = 0.01 and increased dry matter yield. Baque et al, (2006) also reported a significant increase in dry matter, grain yield, tillers in wheat and this increase was significantly high where the potassium rates were increasing. Mengel and Kirkby (1987) confirmed that a significant increase in plant dry matter in potassium treated plants is because of the increase in biochemical pathways, improved translocation processes and an improvement in nitrogen uptake. This may explain the increase in dry matter in this treatment. This is also similar to results by Yiadegari and Rahaman (2010); Bambara and Ndakidemi, (2010) and Mohammadi *et al*. (2013) in which positive responses of dry matter of pods was observed in seed inoculated with rhizobium. These results confirm the importance of rhizobium on dry matter of pods which may be attributed to an increase in nitrogen uptake from 33 to 66% (Konde *et al.,* 1980) which leads to an increase in number of pods and subsequently dry matter of pods.

Seed yield was significantly increased by macronutrients (Mac) application and macronutrient and micronutrient combination (Mac x Mic). Among macronutrients NPK fertilizer had a mean of 1500kg/ha (Table 4.18). The value was not that much different with other macronutrients fertilizers without combining with micronutrient, except Ca which affected negatively seed yield. However, significant increment in yield was observed on those treatments supplied with NPK fertilizer (Table 4.18).

Higher value of seed yield per hectare (2100kg/ha) was observed when NP fertilizer was applied in presence of molybdenum fertilizer (Table Table 4.18). These results conform to the results from rainfed data where a significant increment of seed yield was also recorded in NPK x Mo fertilizer application treatments on common beans. According to the Olaposi and Adarabioyo (2010), by increasing NPK fertilizer rate on legume production, flower and pods formation increases, flower abscission reduces and this increases seed yield. Similarly, a high and significant response was reported on grain yield per hectare on wheat crop in response to NPK application by Malghani et al. (2010). In addition, Achakzai *et al.* (2002) research showed that NPK treatments played an important role on seed yield increment compared with control treatments, but between fertilizer treatments, the data was not found to be significant. This increase in grain yield can be explained by the increase in chlorophyll content, dry matter yield, and number of nodules which subsequently increases grain yield.

Table 4.12: Macronutrient and micronutrients effect on Chlorophyll content in the plant

Fertilizers	ZnS	Mo	B	Control	Mean
N	38	37	37	37	37^{ab}
P	40	39	40	39	40^{ab}
K	37	36	36	36	36^{a}
Ca	38	37	35	38	$37a^{b}$
Rz	38	35	38	36	$37a^{b}$
NP	39	39	39	39	$39a^{b}$
NPK	38	38	48	58	46^{b}
NPRz	37	38	38	36	37^{ab}
Control	37	38	37	38	$38a^{b}$
Mean	38^{a}	37^{a}	39^{a}	40^{a}	$38a^{b}$

	P values	SE	LSD
Mac	0.05	2.946	6.245
Mic	ns	0.937	1.878
Mac x Mic	ns	3.821	7.724
CV%			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.13: Macronutrient and micronutrients effect on number of nodules in the plant

Fertilizer	ZnS	Mo	B	Control	Mean
N	32	32	27	20	28^{ab}
P	106	197	115	131	137^{e}
K	90	100	67	24	70^{cd}
Ca	9	3	9	8	7^{a}
Rz	102	48	92	114	89^{cde}
NP	38	89	53	80	65^{bc}
NPK	72	55	59	101	72^{cd}
NPRz	79	68	52	54	$63b^{cd}$
Control	59	115	107	92	93^{de}
Mean	65^{a}	79^{a}	65^{a}	69^{a}	69^{a}

	P values	SE	LSD
Mac	0.05	13.11	39.32
Mic	ns	9.12	25.86
Mac x Mic	<0.001	27.08	76.39
CV%			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.14: Macronutrient and micronutrients effect on fresh weight of nodules

Fertilizer	ZnS	Mo	B	Control	Mean
N	0.2	0.2	0.13	0.8	0.33^{ab}
P	1.2	2	1.03	0.03	1.06^{d}
K	0.5	1.03	0.5	1.5	0.88^{bc}
Ca	0.06	0.03	0.06	0	0.03^{a}
Rz	1	0.3	0.4	1	0.67^{bc}
NP	0.5	0.5	0.3	0.6	0.47^{abc}
NPK	0.7	0.6	0.4	1.5	0.8^{c}
NPRz	0.6	0.4	0.4	0.3	0.43^{abc}
Control	0.5	1.1	0.9	0.8	0.82^{c}
Mean	0.58^{a}	0.68^{a}	0.46^{a}	0.72^{a}	0.49

	P values	SE	LSD
Mac	0.04	0.1887	0.5657
Mic	ns	0.1198	0.3398
Mac X Mic	<0.01	0.3641	1.0271
CV% 12.8			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.15: Macronutrients and micronutrients effect on dry matter of leaves

Fertilizer	ZnS	Mo	B	Control	Mean
N	20	23.7	23	19.6	22^{a}
P	20.5	23.7	22	21.6	22^{a}
K	37.3	20.2	85	22.7	43^{b}
Ca	18.6	20.1	19	19.2	19^{a}
Rz	22.6	21.6	21	19.8	21^{a}
NP	22.5	18.9	18	23.2	21^{a}
NPK	26.6	26.3	27	54.4	$25a^{b}$
NPRz	25.6	22.8	26	19.1	$33a^{b}$
Control	20.5	20.3	21	22.4	21^{a}
Mean	24^{a}	22^{a}	29^{a}	25^{a}	25^{a}

	P values	SE	LSD
Mac	0.02	12	18.4
Mic	ns	27	10.7
Mac x Mic	ns	3	32
CV% 19.4			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.16: Macronutrients and micronutrients effect on dry matter of stems

Fertilizer	ZnS	Mo	B	Control	Mean
N	65.6	55.2	39.5	38.1	50^{ab}
P	33.7	38.6	26.5	18.9	29^{a}
K	50	31.2	98.8	99.4	70b
Ca	48.9	38	53	53	48^{ab}
Rz	56.6	54.3	61.4	55.8	57^{ab}
NP	24	28	21	21	24^{a}
NPK	41.9	30.6	27.9	20.2	30^{a}
NPRz	27.4	31.4	35.7	29.1	31^{a}
Control	48.9	32.6	26.3	50	39^{a}
Mean	44^{a}	38^{a}	43^{a}	43^{a}	42^{a}

	P values	SE	LSD
Mac	0.03	11.6	34.6
Mic	ns	5.5	15.7
Mac x Mic	ns	18.4	52.1
CV% 68.4			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.17: Macronutrients and micronutrients effect on dry matter of pods

Fertilizer	ZnS	Mo	B	Control	Mean
N	29.1	30.22	27.7	24.8	28[ab]
P	24.7	24.1	27	28.4	26[ab]
K	24.6	23.3	34.6	26	27[ab]
Ca	15.1	14.1	17.3	20.7	17[a]
Rz	36.2	47.5	19.2	92.2	49[b]
NP	37	36	28	27	32[ab]
NPK	49.3	20.2	24.1	19.5	28[ab]
NPRz	23.4	22.4	23.7	21.8	23[ab]
Control	23.5	25.5	23.4	25.7	25[ab]
Mean	29[a]	27[a]	25[a]	32[a]	28[a]

	P values	SE	LSD
Mac	0.03	7.4	22.2
Mic	ns	4.6	12.9
Mac x Mic	ns	13.9	39.4
CV% 84.3			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.18: Macronutrients and micronutrients effect on grain yield (kg/ha)

Fertilizer	ZnS	Mo	B	Control	Mean
N	698	671	676	691	684[ab]
P	778	1000	680	750	802[ab]
K	704	947	647	758	764[ab]
Ca	275	344	333	387	335[a]
Rz	873	884	884	940	895a[b]
NP	856	2100	950	813	1180[b]
NPK	836	880	851	1500	1017[b]
NPRz	100	1100	710	900	703a[b]
Control	576	676	602	500	589a[b]
Mean	633[a]	956[a]	704[a]	804[a]	774[a]

	P values	SE	LSD
Mac	<0.01	90.3	270
Mic	ns	75.4	214
Mac x Mic	0.01	216	609
CV% 19.6			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

4.2.2 Effect of macronutrients and micronutrients on grain yield and yield components on bush beans under drought stress condition

Results (Tables 4.19, 4.20, 4.21, 4.22 and 4.23) showed macronutrient (Mac) had significant effect on chlorophyll content in the leaves ($P < 0.05$), number of nodules per plant ($P < 0.001$), fresh weight of nodules ($P < 0.01$), both number of pods per plant and 100-seed weight($P < 0.05$) and seed yield per hectare($P < 0.001$).There was a significant interaction between macronutrients and micronutrients (Mac x Mic) on 100 seed weight ($P < 0.05$) (Table 4.23). Micronutrient (Mic) application had effect on two traits; number of nodules per plant and fresh weight of nodules both at $P < 0.05$ level(Tables 4.20 and 4.21).Furthermore, the greater percentage of chlorophyll content in the leaves was observed on treatments without fertilizer supplement (control) with 60% of chlorophyll in their leaves. The other fertilizer treatments did not differ in terms of chlorophyll content in their leaves (Table4.19).

Results by Nleya *et al*. (2001) showed that fertilizer supplement on common beans can improve drought tolerance capacity by increasing photosynthetic products and early plant flowering followed by early seed maturity. For instance, potassium fertilizers are reported to improve water relations, biochemical processes, osmotic potential, translocation processes, growth and maintenance of cells (Islam *et al.*, 2004) and subsequently improve plant productivity under water stress environments (Mengel and Kirkby, 1987).

Apart from potassium and other elements, nitrogen has been reported to reduce the effects of drought stress on crop growth and development (Raun and Johnson, 1999). Heckathorn et al. (1997) further reported that application of nitrogen increases photosynthetic capacity of the leaves by increasing stromal and thylakoid proteins in leaves and this is very important in drought tolerance for plants. However, these results are contradictory to the results from this study where macronutrient application resulted in lower chlorophyll content in the leaves than in control plants. Perhaps the increase in the chlorophyll content in control plants might be attributed to the variety that was used in this trial which exhibited some characteristics of drought tolerance such it influenced significantly high chlorophyll content and yield compared to the treatments which had fertilizers. In addition, it might also be because the soil was severely stressed which reduced mass flow of nutrients and in turn reduced uptake (Garg, 2003).

Negative and positive effects were observed on nodule number and fresh weight of nodules by macronutrient (Mac) application. Calcium and nitrogen fertilizers (Ca and N) alone, negatively affected the number of nodule and nodule fresh weight. Small mean performance on those two traits was observed on treatments with N and Ca fertilizer application where the number of nodules was smaller than the control. However, higher nodule number (160 nodules) and nodule weight (1.2g) by treatments with P fertilizer only was observed (Table 4.20).

Significant interactions were also observed between phosphorus and molybdenum (P + Mo) on nodule number (176 nodules/plant) and nodule weight (1.8g), followed by interaction between rhizobium and molybdenum (Rz + Mo) application on nodules number and nodule weight (Tables 4.20 and 4.21).The result for number of nodule per plant sampled from fertilized and stress trial did not differ much with those on irrigated trial. This can be explained by the fact that nodule sampling was done, 6 weeks after planting and close to flowering and before withholding water was implemented. High number of nodules on legume crop was influenced by molybdenum and P fertilizer application and this has also been reported by (Mfilinge *et al.*, 2014; Elkoca, *et al.,* 2007; Zahran, 1999).The role of phosphorous and molybdenum in energy supply for nitrogenase activities and as a component of nitrogenase in nitrogen fixation, respectively, explains the significantly higher number of nodules in these treatments.

A significantly lower mean on number of pods was observed in treatments with calcium (extra-cal) fertilizer application under water stress and this was followed by K fertilizer application. However, a higher mean on number of pods was observed in treatments where seed was inoculated with rhizobium inoculant (Table 4.22).

Results from macronutrient and micronutrient interaction (Mac x Mic) showed positive effects on number of pods per plant. Treatments with seed inoculated with rhizobium and NP fertilizer in presence of molybdenum (NPRz + Mo) had more number of pods followed by treatments with seed inoculated with rhizobium in presence of molybdenum (Rz + Mo) (Table).The role of nitrogen, phosphorus, rhizobium (Kannaiyan, 2002) and molybdenum (Biscaro *et al*., 2009) in nodule formation, photosynthesis subsequently resulted into higher number of pods observed in this study.

Potassium fertilizer (K) and rhizobium inoculant treatments (Rz) exhibited positive influence on 100-seed weight. A significantly higher mean performance on 100-seed weight was contributed to K fertilizer (0.3g) and rhizobium inoculant (0.2g) (Table 4.23). The influence of K fertilizer on 100-seed weight was enhanced by ZnS fertilizer (0.5g) treatment.

Grain yield was significantly and negatively affected by Ca (102 kg/ha) which increased with rhizobium inoculant (940 kg/ha)(Table 4.24).The macro-micronutrients interaction had significant reduction of seed yield for bush beans in drought stress trial in almost all fertilizer treatments. High grain yield were recorded from treatments where K fertilizer was applied in combination with molybdenum (947 kg/ha); followed by treatments where seed was coated with rhizobium only (940 kg); and this was followed by seed inoculated with rhizobium in combination with molybdenum (884kg/ha) (Table 4.24).

A decrease in number of pods per plant as well a 100- seed weight under drought conditions directly reduced seed yield. Szilagyi, 2003; Singh, 2007; Rosale-Serna et al, 2004 found that grain reduction under drought stress is strongly correlated with number of pods per plant as well 100-seed weight. Rhizobium inoculant and molybdenum played important role on these three parameters: number of pods per plant;100-seed weight; and seed yield under drought conditions; their contributions increases yield per hectare. An increase on number of pods per plant and 100-seedweight due to rhizobium inoculant application on the seed of common beans (*Phaseolus vulgaris* L.), has been reported by Mfilinge *et al*. (2014). Findings on increase in number of pods per plant on those treatments inoculated with Rhizobium which was attributed to better plant development and establishment was reported on mugbean (*Vigna radiata* L.) and common bean (*Phaseolus vulgaris* L.) by Ashraf *et al*. (2003) and Ali et al. (2000); respectively.

Table 4.19: Macronutrients and micronutrients effect on chlorophyll content on the leaves

Fertilizer	ZnS	Mo	B	Control	Mean
N	38	38	39	39	39[a]
P	40	41	40	39	40[a]
K	37	39	39	40	39[a]
Ca	41	40	41	40	41[a]
Rz	40	40	39	40	40[a]
NP	41	40	39	41	40[a]
NPK	40	40	40	39	40[a]
NPRz	38	39	39	39	39[a]
Control	41	41	40	85	52[b]
Mean	40[a]	40[a]	40[a]	45[a]	41[a]

	P values	SE	LSD
Mac	0.02	1.8	5.5
Mic	ns	1	2.8
Mac X Mic	ns	3.2	9
CV% 13			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.20: Macronutrient and micronutrients effect on number of nodules in the plan

Fertilizer	ZnS	Mo	B	Control	Mean
N	59	37	59	12	42[ab]
P	80	176	134	155	136[c]
K	73	141	123	84	105[bc]
Ca	36	9	33	19	24[a]
Rz	112	150	71	104	109[bc]
NP	41	126	84	60	78a[bc]
NPK	64	111	65	44	71a[bc]
NPRz	81	61	92	48	71a[bc]
Control	67	156	89	80	98[bc]
Mean	68[a]	107[ab]	83[a]	67[a]	82[a]

	P values	SE	LSD
Mac	<0.001	21	45
Mic	0.09	11	23
Mac X Mic	0.08	37	73
CV% 58			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.21: Macronutrient and micronutrient effect on nodule fresh weight

Fertilizer	ZnS	Mo	B	Control	Mean
N	0.2	0.4	0.3	0.03	0.23[a]
P	0.8	1.8	0.3	1.2	1.13[b]
K	0.8	0.8	0.7	0.5	0.74[ab]
Ca	0.01	0.01	0.01	0.01	0.13[ab]
Rz	0.8	1	0.4	0.9	0.58[ab]
NP	0.4	0.5	0.6	0.5	0.65[ab]
NPK	0.4	0.4	0.3	0.1	0.33[ab]
NPRz	0.5	0.3	0.7	0.3	0.48[ab]
Control	0.7	1.1	0.5	0.3	0.57[ab]
Mean	0.6[a]	1.2[b]	0.5[a]	0.5[a]	1.1[b]

	P values	SE	LSD
Mac	<0.01	0.15	0.46
Mic	0.08	0.07	0.199
Mac x Mic	0.09	0.23	0.67
CV% 67			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.22: Macronutrients and micronutrients effect on pod number

Fertilizer	ZnS	Mo	B	Control	Mean
N	57	60	55	62	59[ab]
P	71	60	52	55	60[ab]
K	41	51	63	37	48[ab]
Ca	25	27	28	25	26[a]
Rz	73	79	66	64	71[b]
NP	69	70	63	59	65[ab]
NPK	69	47	62	64	61[ab]
NPRz	68	87	65	70	73[ab]
Control	52	70	49	37	52[ab]
Mean	58[a]	61[a]	56[a]	53[a]	57[a]

	P values	SE	LSD
Mac	0.09	9.24	27.69
Mic	ns	3.08	8.72
Mac x Mic	0.05	12.21	34.86
CV% 27			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.23: Macronutrients and micronutrients effect on 100 seed weight (g)

Fertilizer	ZnS	Mo	B	Control	Mean
N	0.06	0.06	0.06	0.06	0.06[a]
P	0.06	0.06	0.06	0.06	0.06[a]
K	0.5	0.06	0.06	0.03	0.20[b]
Ca	0.04	0.06	0.06	0.06	0.06[a]
Rz	0.06	0.06	0.06	0.2	0.10[ab]
NP	0.06	0.06	0.06	0.06	0.06[a]
NPK	0.06	0.06	0.06	0.06	0.06[a]
NPRz	0.06	0.06	0.06	0.06	0.06[a]
Control	0.06	0.06	0.06	0.06	0.06[a]
Mean	0.11[ab]	0.06[a]	0.06[a]	0.07[a]	0.08

	P values	SE	LSD
Mac	0.02	0.03	0.098
Mic	ns	0.02	0.068
Mac x Mic	0.07	0.07	0.197
CV% 13			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.24: Macronutrients and micronutrients effect on grain yield (kg/ha)

Fertilizer	ZnS	Mo	B	Control	Mean
N	506	290	324	86	301.5[a]
P	315	647	580	733	568.8[ab]
K	275	830	468	488	545[ab]
Ca	249	322	324	102	249.3[a]
Rz	707	947	742	940	804.5[b]
NP	102	577	700	404	445.8a[b]
NPK	81	689	760	664	548.5[ab]
NPRz	480	676	682	664	625.5[b]
Control	420	500	75	75	267.5[a]
Mean	348[a]	609.1[ab]	517[ab]	462[a]	469.5[a]

	P values	SE	LSD
Mac	<0.001	68.7	205.8
Mic	ns	31.2	88.6
Mac x Mic	ns	106.3	300.9
CV% 27.5			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

4.2.3.1Correlations among traits of bush bean under well watered (ww) and drought stress conditions at Kandiyani dam.

Significantly high correlation (P≤0,001) was observed on number of nodules per plant, fresh weight of nodules, number of pods per plant and dry matter of leaves to seed yield (kg/ha). Chlorophyll content in the leaves was positively correlated with seed yield (kg/ha) under well watered trial. Highest negative correlation with seed yield (kg/ha) was observed on days from planting to flowering, percentage of dry matter of stems, 100-seed weight and harvest index (Table 4.26).

In the water stress trial, strong correlation (P≤0,001) were observed between number of days to emergence; fresh weight of nodules; and number of pods per plant to seed yield (kg/ha). Meanwhile significant negative correlations to seed yield per hectare were observed on days to flowering; chlorophyll content; dry matter of leaves stems and pod weight. Number of nodules and 100-seed weight was positively correlated to seed yield per hectare (Table 4.26).

Among the components that are important for drought tolerance, number of pods per plant and 100-seed weight can be considered as critical parameters. A decrease in number of nodules per plant and 100-seed weight automatically reduces seed yield. Strong correlation between number of pods and seed yield under drought stress trials can also be observed on the performance on those two parameters, high number of pods per treatment resulted in high yield per hectare (Table 4.26). These results were similar to those found by Szilagyi (2003), where seed yield was highly associated with number of pods per plant. Positive correlation between chlorophyll to seed yield under irrigation, can be attributed to the ability of expanded leaves as source of photosynthate to support flowers and pods while under moisture stress chlorophyll content in the leaves was negative but strongly correlated with seed yield per hectare. The negative correlation results in chlorophyll content can be explained by reduced plant canopy in which the ability of leaves as a source of photosynthate is reduced (Asfaw *et al.;* 2012)

Table 4.26: Correlation among agronomic traits measured in Kandiani on bush beans type. Top diagonal (bold) represent stressed trial (WS) and bottom diagonal well watered (WW) trial.

	EC	DF	Chl	NN	NW	PN	DML	DMP	DMS	100SW	HI	YH
EC	1	-0.13*	0.014	0.03	0.023	0.23***	0.075	-0.25***	0.19**	-0.03	-0.09	0.26***
Df	0.13*	1	-0.048	- 0.22 ***	-0.15**	0.25***	0.16**	0.25***	-0.12*	-0.02	0.39***	-0.36***
Chl	0.009	0.027	1	0.21***	0.03	0.25***	0.21***	-0.001	0.35***	-0.13*	0.18*	-0.20***
NN	-0.042	-0.36	-0.02	1	0.83***	0.08	0.16**	0.09	0.10*	0.07	-0.15**	0.19**
NW	-0.045	-0.27	-0.002	0.89***	1	0.06	0.08	0.12*	0.098	0.07	-0.11*	0.21***
PN	-0.13*	-0.50****	0.08	0.19**	0.21***	1	-0.47	0.13*	-0.07	-0.008	0.47***	0.55***
LDM	0.16**	-0.04	-0.07	-0.02	-0.04	0.015	1	0.14*	0.19**	0.08	0.40***	-0.31***
PDM	-0.007	-0.15**	-0.09	0.06	-0.007	0.013	0.07	1	-0.07	0.03	0.34***	-0.03
SDM	0.17**	0.11*	-0.008	0.02	-0.02	0.35***	0.03	0.12*	1	-0.08	0.08	-0.12*
100SW	0.050	0.80***	-0.06	-0.40***	- 0.30***	0.52***	-0.10*	-0.17**	0.06	1	-0.08	0.12*
HI	0.097	0.34	-0.10*	-0.10*	-0.15**	0.45***	0.27***	0.18**	0.50***	0.30***	1	-0.70
YH	0.076	-0.52***	0.11*	0.23***	0.23***	0.58***	0.02***	0.08	-0.18**	-0.61***	-0.61***	1

Key: EC= emergence count, NN= number of nodules, NW=nodule weight, DF=days to flowering, Chl=chlorophyll content, LDM= leave dry matter, SDM= stems dry matter, PDM=pod dry matter, 100SW=weight of hundred seeds, HI=Harvest index, YH=Yield per hectare, *P≤0.05, **P≤0.01, ***P≤0,001

4.2.4 Combined analysis across 2 water regime on bush beans

The combined analysis of variance across two water regimes showed that days from planting to flowering and number of nodules were highly significantly ($P<0.001$) influenced by macronutrient application. In addition, on these traits, the number of pods, 100-seed weight, seed yield (kg/ha) and harvest index was significantly influenced by macro nutrients and micronutrients combination in bush beans trials (Table 4.22).

Macronutrient effect made largest percentage variation of (55, 5%, 40.5% and 35.2%) observed 100-seed weight, number of pods, and seed yield per hectare on bush beans type; respectively. However, variations accounted by number of nodules per plant and harvest index were below 10% (Table 27). Mac and Mic nutrients combination also influenced the number of pods, 100seed weight and seed yield per hectare, the variation accounted for 35, 60 and 25% respectively (Table 4.22).

Table 4.27: Combined analysis of variance for agronomic data measured from bush beans trials at Kandiyani dam.

Days to flowering					Number of nodules					Number of pods				
Source	df	M.S	Fpr.	%explained	Source	df	M.S	Fpr.	%explained	Source	df	M.S	Fpr.	%explained
W.r	1	4.222			W. r	1	224			W.r	1	582		
Mac	8	133.17	<0.001	26.6	Mac	8	8392	<0.001	5.6	Mac	8	10590	<0.001	40.5
error a	40	5.233			error a	40	2459			error a	40	2660		
Mic	3	3.274	0.491	0.81	Mic	3	808	0.529	0.74	Mic	3	27	0.0994	1.45
mac x mic	24	5.843	0.95	0.56	mac x mic	24	963	0.624	0.88	mac x mic	24	1547	0.05	35
error b	135	5.843			error b	135	1090			error b	135	1070		
Total	215				Total	215				Total	215			
100 seed weight (g)					Yield (kg/ha)					Harvest index				
Source	df	M.S	Fpr.	%explained	Source	df	M.S	Fpr.	%explained	Source	df	M.S	Fpr.	%explained
W.r	1	0.1583			W.r	1	128074			W.r	1	0.00535		
Mac	8	2439.653	<.001	55.5	Mac	8	70558	<.001	35.2	Mac	8	0.10156	<0.001	5.7
error a	40	488.8173			error a	40	74205			error a	40	0.01963		
Mic	3	1.2933	0.112	0.122	Mic	3	33767	0.05	22.3	Mic	3	0.04551	0.05	3.9
mac x mic	24	1.2664	<0.001	60.1	mac x mic	24	26352	0.05	25.5	mac x mic	24	0.01463	0.208	1.26
error b	135	0.6356			error b	135	26062			error b	135	0.01166		
Total	215				Total	215				Total	215			

Key: d.f- degree of freedom; M.S- mean square, Fpr- F probability, %explained-percentage variation explained by sum of squares; Wr-water regime, Mac- macronutrients, Mic- micronutrients

4.2.5 Effect of macronutrients and micronutrients application on grain yield and yield components on climber beans in well watered trial at Kandiyani

The results in Table 4.28 showed significant response to macronutrient (Mac) application and macronutrient x micronutrient (Mac x Mic) combination ($P < 0.05$) on number of nodules per plant (NN). Macronutrient ($P< 0.05$) and (Mac x Mic) combination affected fresh weight of nodules (NW) ($P < 0.01$); and number of pods per plant (PN) ($P <0.001$), respectively (Tables 4.29 and 4.30). In addition both macronutrient (Mac) application ($P < 0.01$) and macronutrient x micronutrient (Mac x Mic) ($P < 0.05$) interactions significantly affected seed yield per hectare (Table 4.31).

Macronutrients (Mac) such as P and Ca fertilizer, combination of macronutrients such as NP fertilizers and combination of macronutrient and micronutrient (Mac x Mic) fertilizer such as NP + Mo significantly increased the number of nodules per plant and fresh weight of nodules (Tables 4.28 and 4.29). The lowest number of nodules per plant in treatments with macronutrient (Mac) only was observed in Ca treatment. P fertilizer improved nodule number and weight of nodules per plant (Tables 4.28 and 4.29). The highest number and weight of nodules was observed in the interaction of NPRz + Mo with nodules per plant and fresh weight. These results are contrary to those reported by (Abdul, 2007; Achakzai, 2007) who indicated that the presence of N in fertilizers significantly reduced number and weight of nodules on legume crop under normal water supply conditions. The presence of P and Mo fertilizers in these combinations may explain the increased number of nodules and their weight as they play important roles in nodule formation and nitrogen fixation in legumes (Biscaro et al., 2009).

Presence of P fertilizer among the 36 treatments significantly influenced pod number and seed yield per hectare. In treatments where P fertilizer was applied or was in combination with other nutrients, there was significantly higher number of pods than any other treatment. On the other hand, the other treatments where P was not present had approximately same mean in pod number per plant (Table 4.30).

However, macronutrient and micronutrients (Mac x Mic) combination, NPRz +Mo had significantly high number of pods per plant (76) and consequently high seed yield (1500kg/ha), followed by NPK + Mo treatments with 73 pods per plant and 1009kg/ha seed yield. The macro and micro nutrient combination where P and Rz were involved resulted in significantly higher number of pods per plant and subsequently a significantly higher seed yield than any other treatment. The significant yield increase achieved in NPRz + Mo treatments may be explained by the roles of P, N, Rz and Mo in plant growth and development such as energy transfer, synthesis of nitrogenase enzyme, nitrogen fixation and synthesis of proteins respectively, which result increased nodulation, increases on number of nodules, pod number and pod weight and consequently higher seed yield per hectare (Biscaro *et al.,* 2009). Similarly, (Abdel-Mawgoud et al., 2005) confirmed that supplementation of NPK or NP fertilizer increased yield of beans.

Table 4. 28: Macronutrient and micronutrients effect on number of nodules in the plant

Fertilizer	ZnS	Mo	B	Control	Mean
N	16	30	13	31	23a
P	39	113	8	107	67ab
K	34	84	35	13	42ab
Ca	2	31	5	1	10a
Rz	47	61	45	101	64
NP	60	113	28	113	79ab
NPK	33	90	45	118	72ab
NPRz	63	135	48	15	65ab
Control	27	87	74	31	55ab
Mean	36a	83ab	33a	59ab	53

	P values	SE	LSD
Mac	0.06	28.43	85.23
Mic	ns	9.65	27.37
Mac x Mic	0.03	37.91	108.13
CV% 9.5			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4 29: Macronutrients and micronutrients effect on fresh weight of nodules (g)

Fertilizer	ZnS	Mo	B	Control	Mean
N	0.1	0.0	0.1	0.1	0.1b
P	0.3	0.4	0.0	0.8	0.4ab
K	0.3	0.1	0.8	0.1	0.3ab
Ca	0.1	0	0	0	0.02a
Rz	0.2	0.1	0.1	0.5	0.2ab
NP	0.4	0.9	0.1	0.4	0.5abc
NPK	0.2	0.2	0.2	0.6	0.3ab
NPRz	0.4	2.5	0.2	0.1	1.0c
Control	0.1	0.4	0.3	0.1	0.2b
Mean	0.2b	1.0a	02b	0.3b	0.3

	P values	SE	LSD
Mac	0.07	0.2	0.7
Mic	ns	0.1	0.4
Mac x Mic	0.01	0.4	1.2
CV% 58			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.30: Macronutrients and micronutrients effect on number of pods

Fertilizer	ZnS	Mo	B	Control	Mean
N	54	66	53	50	56^{bc}
P	48	61	64	68	60^{bc}
K	51	29	45	31	39^{ab}
Ca	23	32	33	36	31^{a}
Rz	54	41	50	64	52^{abc}
NP	57	59	45	53	54^{abc}
NPK	59	73	63	49	61^{bc}
NPRz	56	76	65	58	64^{c}
Control	47	45	63	30	46^{abc}
Mean	50a	54a	53a	49a	51

	P values	SE	LSD
Mac	0.03	4.13	12.39
Mic	ns	2.82	7.99
Mac x Mic	<0.001	8.4	23.71
CV% 28.4			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.31: macronutrients and micronutrients effect on seed yield (Kg/ha)

Fertilizer	ZnS	Mo	B	Control	Mean
N	504	567	522	509	526^{ab}
P	647	711	513	731	651^{ab}
K	589	524	549	511	543^{ab}
Ca	216	322	424	311	318^{a}
Rz	511	269	480	496	439^{ab}
NP	751	780	580	676	697^{ab}
NPK	757	1009	660	833	815^{b}
NPRz	742	1500	524	597	841^{b}
Control	518	631	633	449	558^{ab}
Mean	582^{a}	701^{b}	543^{a}	568^{a}	599^{a}

	P values	SE	LSD
Mac	<0.01	58.9	176.6
Mic	ns	36.1	102.5
Mac X Mic	0.08	110.9	312.8
CV% 3.9			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

4.2.6Effectof macronutrients and micronutrients on grain yield and yield components on climber beans under drought stress condition at Kandiyani dam

Macronutrient (Mac) application significantly affected number of days to flowering ($P < 0.01$), nodule number per plant, fresh nodules weight, and also at ($P< 0.05$) for seed yield per hectare (Tables 4.34, 4.33, 4.34 and 4.36). There were also significant responses in number of nodules per plant and fresh nodule weight by macronutrient and micronutrient application (Mac x Mic) at $P = 0.05$ (Tables 4.33 and 4.34).

Both macronutrients (Mac) and Mac x Mic combination were significant at $P < 0.05$ and $P < 0.01$ on number of pods per plant, respectively (Table 4.36). Micronutrients (Mic) alone did not make any significant difference on yield and yield components on climber beans under to drought condition.

Although the performance of common beans under water stress was not as comparable to well watered (WW) trial, almost same components or traits which were statistically significant on climber beans in well watered condition (WW) were also significant on drought stress (DS) trial. Number of days to flowering was significant at $P = 0.05$.The significance was observed to be negative and it was also noted that those treatments which were applied with calcium extra-cal took more days to flowering than control and other treatments (Table 4.34).

The response on number of nodules and nodule weight by macronutrient (Mac) addition can be justified by P fertilizer application which had a mean performance of 120 nodules per plant and 2.2g fresh weight. The mean performance of nodule number per plant and nodule weight was higher than the overall mean of all treatments (Tables 4.33 and 4.34).

Macronutrient and micronutrient combination (Mac x Mic) had significant and positive effect on number of nodules and fresh weight. P + Mo treatment had significantly highest mean number of nodules (141) per plant and 2.4g fresh weight of nodules. Rhizobium inoculant plus molybdenum (Rz + Mo) was one of the treatments which had performed better in terms of nodule number (100) and higher weight of nodules among 36 treatments (3.0g) (Tables 4.33 and 4.34).

Similar results were found on the same experiment in a bush beans variety. Phosphorus fertilizer, Rhizobium inoculant and molybdenum played significant roles in increasing number of nodules and nodule weight. Similarly, research on chickpea response to molybdenum alone and combined application of molybdenum with rhizobium, showed an increase on number of nodules and nodule fresh weight (Mfilinge *et al.*, 2014; John et*. al*., 2000). According to Das et al. (2012), a combination of rhizobium with sodium molybdate not only increased number of nodules but also increased plant dry matter, grain yield and N and P uptake.

The results in this study can hence be explained by the role of molybdenum and its interaction with the inoculant and native rhizosphere, root colonization and hair infection and their efficiency on nitrogen fixation. The increase in number of nodules in the presence of molybdenum fertilizer can also be related to nitrogenase activities which take place in the nodule by presence of molybdenum (Biscaro et al, 2009). Although there were significant differences on the number of pods per plant, this trait did not differ much in almost all fertilizer treatments. However, amongst all the treatments i.e. Ca fertilizer treatments and where Ca interaction with micronutrients had the lowest number of pods per plant (14, 17, 18, and 17); respectively, as compared to the overall mean (70) of pod number. These results are in tandem with results by Jarakan et al. (2006) who also reported a decrease on yield and yield component such as plant length, dry matter weight, number of pods and seed yield on common beans. On the other hand, the results from this study are contrary to results by Kabir et al. (2013) which revealed a significant increase in yield and yield components when different levels of calcium were applied in groundnut. The results from this study might be as a result of time of the fertilizer application, rate of the fertilizer, form of fertilizer and also water availability in the soil. Enson and Bliss (1991) stressed on the need for understanding the amount of fertilizers and time of application as being crucial in production of common beans where the results revealed that smaller amounts of inorganic fertilizers at the beginning of the vegetative period is very important.

Macro-micronutrients combination significantly and positively affected pod number. The highest number of pods was found when P was present. However, the highest number of pods was observed when Mo and P were present in macro-micro nutrient combination. For instance, a combination of NPRz + Mo resulted in (416 pods) per plant (Table 4.35). Other studies by Kakar et al. (2002) and (Achakzai and Bangulzai, 2006) confirmed that application of P fertilizers improves pod numbers and yield among other factors. As such the results from this study can be explained by the role of P on plant growth and development in yield of legumes.

The application of calcium fertilizer significantly and negatively affected seed yield per hectare under drought stress condition. Calcium treatment had significantly the lowest yield (101 kg/ha) per hectare and lower mean performance among all treatments than control (338kg/ha) (Table 40). Seed yield per hectare did not show positive significance among all treatments, and the mean yield per hectare was lower in almost all fertilizer treatments than well watered trial. Apart from calcium, yield from the other fertilizer treatments did not significantly differ.

Although there were no significant differences, a higher yield (566 kg/ha), was observed on those treatments with seed treated with rhizobium added NP fertilizer in presence of molybdenum (NPRz + Mo). Although some studies showed that Calcium increased yield and yield components (Kabir *et al.*,2013), the results from this study may be as a result of the time of fertilizer application which should have been applied before vegetative production, the fertilizer form (foliar vs inorganic) and amount of water availability(Jarak *at el*., 2006; Henson and Bliss, 1991).

Table 4.32: Macronutrients and micronutrient effect on days to flowering

Fertilizer	ZnS	Mo	B	Control	Mean

N	51	53	53	52	52^{a}
P	57	52	52	53	54^{a}
K	53	53	52	53	53^{a}
Ca	61	60	52	62	59^{b}
Rz	53	53	52	51	52^{a}
NP	53	53	53	53	53^{a}
NPK	53	52	52	52	52^{a}
NPRz	53	52	52	52	52^{a}
Control	53	52	52	53	53^{a}
Mean	54^{a}	53^{a}	52^{a}	53^{a}	53^{a}

	P values	SE	LSD
Mac	<0.001	0.66	1.98
Mic	ns	0.31	0.87
Mac x Mic	ns	1.03	2.93
CV% 3			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.33: Macronutrient and micronutrients effect on number of nodules per plant

Fertilizer	ZnS	Mo	B	Control	Mean
N	15	5	29	6	14^{ab}
P	66	141	63	120	98^{c}
K	21	24	3	50	25^{ab}
Ca	5	0	0	4	2^{a}
Rz	30	100	48	67	61^{abc}
NP	63	84	60	43	63^{abc}
NPK	64	103	39	82	72^{bc}
NPRz	49	78	48	57	58^{abc}
Control	27	18	14	27	22^{ab}
Mean	38^{a}	61^{b}	34^{a}	51^{ab}	46

	P values	SE	LSD
Mac	<0.001	13.38	40.12
Mic	ns	7.96	22.57
Mac x Mic	0.07	24.64	69.52
CV% 50			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.34: Macronutrients and micronutrients effect on nodule fresh weight (g)

Fertilizer	ZnS	Mo	B	Control	Mean

N	0.03	0.1	0.06	0.03	0.1^{a}
P	0.2	2.5	0.4	2.20	1.33^{b}
K	0.03	0.1	0	0.2	0.1^{a}
Ca	0	0	0	0.03	0^{a}
Rz	0.1	3	0.4	0.4	0.1^{a}
NP	0.2	0.2	0.1	0.1	0.2^{a}
NPK	0.2	0.4	0.1	0.2	0.2^{a}
NPRz	0.1	0.8	0.3	0.03	0.3^{a}
Control	0.06	0.04	0.06	0.1	0.1^{a}
Mean	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}

	P values	SE	LSD
Mac	<0.001	0.286	0.8574
Mic	ns	0.1622	0.4599
Mac x Mic	0.05	0.5093	1.4376
CV%101			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 4.35: Macronutrients and micronutrients effect on number of pods per plant

Fertilizer	ZnS	Mo	B	Control	Mean
N	81	79	75	79	79^{ab}
P	37	141	49	55	71^{ab}
K	47	70	48	61	57^{ab}
Ca	17	24	14	18	18^{a}
Rz	55	60	63	51	57^{ab}
NP	62	46	55	67	58^{b}
NPK	93	81	61	52	72^{ab}
NPRz	104	416	106	49	169^{c}
Control	70	55	61	47	58^{b}
Mean	63^{ab}	108^{b}	59^{ab}	53^{a}	71^{ab}

	P values	SE	LSD
Mac	0.05	31.7	44.9
Mic	ns	20.2	28.5
Mac x Mic	<0.001	61.3	86.6
CV%150			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

Table 36: Macronutrients and micronutrients effects on seed yield (Kg/ha)

Fertilizer	ZnS	Mo	B	Control	Mean

N	500	535	516	471	506c
P	359	477	289	373	375ab
K	271	402	524	326	381ab
Ca	104	101	133	131	117a
Rz	482	188	387	366	356ab
NP	496	384	335	435	413abc
NPK	496	353	458	429	434abc
NPRz	504	566	513	406	497abc
Control	438	500	471	338	437abc
Mean	406[a]	390[a]	403[a]	364[a]	390[a]

	P values	SE	LSD
Mac	0.09	59.34	177.9
Mic	ns	18.01	51.07
Mac x Mic	ns	75.57	216.4
CV% 31			

Key: Mac= macronutrients; Mic= micronutrients; SE= Standard Error of the Difference; CV= Coefficient of variation; LSD= Least Significant difference; ns=non significant.
Note: Means with same superscripts are not significantly different.

4.2.6.1 Correlations among traits of climber bean under well watered (ww) and drought stress condition at Kandiyani dam

For the well watered (ww) trial on climbers beans variety, the days to flowering, number of pods per plant and dry matter of leaves was highly and positively correlated (P≤0,001) with seed yield. Significant positive correlation (P≤0, 05) was also observed on nodule fresh weight with seed yield. However, highly significant negative correlations with seed yield per hectare were observed on days to flowering (P≤ -0, 05) and harvest index (P≤ -0,001), respectively(Table 4.37).

From the results of correlation coefficient, studies revealed that under normal water supplies common beans and other different legumes traits such number and weight of fresh pods per plant are a good criterion for predicting seed yield in legumes crops (Akyeampong,1985). Similar results were found by (Bennet *et al.,* 1977; Wallace *et al*., 1972) who reported that grain yield was highly correlated with the pod number in dry bean, and among all traits are related with yield on dry beans. On the high correlation between leaves dry matter to grain yield under well watered trial, this may be related to plants ability to mobilize and translocate photosynthates to the grains.

Negative correlation between number of days from sowing to flowering is in line with results by Sofi *et al*. (2011), who reported that days to flowering, to maturity was negatively correlated with grain yield, but they also reported high correlation between pod numbers per plant and grain yield.

Among the parameters under water stress trial which correlated with seed yield, only number of pods per plant and dry matter on the leaves had strong and positive correlation ($P \leq 0.001$). Although harvest index was highly significant, it was negatively correlated to seed yield ($P \leq$ - 0,001). Negative correlation was also observed between numbers of days to flowering and seed yield per hectare ($P \leq$-0, 05). In addition, fresh weight of nodules was negatively correlated to seed yield per hectare ($P \leq$0, 05) even though the correlation was not strong(Table 4.37).It was also observed that the parameters which correlated positively with seed yield under well watered trial were also correlated positively under water stress trial. This may suggest that the plant functions do not necessarily change under different environments, but the differences in amount of parameters such as yield, number of pods, chlorophyll content, and dry matter among others may be as a result of the presence or absence of limiting factors i.e. water availability, nutrient availability, temperature among other factors (Uchida et al., 2000).

Table 4.37: Correlation among agronomic traits measured in Kandiyani dam on climber beans. Top horizontal (bold) represent stressed trial (WS) and bottom vertical represent well watered (WW) trial.

	EC	**Df**	**Chl**	**NN**	**NW**	**PN**	**LDM**	**PDM**	**DMS**	**100SW**	HI	YH
EC	1	**-0.26*****	**0.02**	**-0.069**	**0.05**	**0.11***	**0.02**	**-0.03**	**0.02**	**0.23*****	**-0.11***	**0.06**
Df	-0.17*	1	**-0.008**	**-0.104**	**-0.06**	**-0.15***	**0.04**	**-0.18***	**0.06**	**-0.41*****	**0.29*****	**-0.19***
Chl	0.16*	-0.06	1	**0.06**	**-0.04**	**-0.06**	**0.02**	**-0.01**	**0.003**	**0.09**	**-0.02**	**-0.06**
NN	-0.03	-0.13*	-0.003	1	**0.33*****	**0.03**	**0.17***	**0.02**	**0.042**	**0.03**	**-0.008**	**0.08**
NW	0.02	-0.07	0.03	0.33***	1	**-0.01**	**0.06**	**0.0007**	**0.02**	**-0.07**	**0.18***	**-0.11***
PN	-0.12*	0.02	0.09	-0.09	0.10*	1	**-0.04**	**-0.09**	**-0.09**	**0.35*****	**-0.22*****	**0.28*****
LDM	0.16*	-0.13*	0.001	0.17*	0.05	0.24***	1	**-0.04**	**0.50*****	**0.02**	**0.41*****	**0.10***
PDM	-0.15*	0.25***	0.04	0.02	0.05	0.22***	-0.053	1	**0.20*****	**0.08**	**0.32*****	**-0.07**
SDM	-0.02	-0.03	-0.02	0.009	0.001	0.12*	-0.04	-0.07	1	**0.01**	**0.51*****	**0.009**
100SW	-0.07	0.04	-0.02	0.02	-0.006	-0.20***	-0.10*	-0.09	0.05	1	**-0.07**	**0.11***
HI	-0.31***	0.23***	0.05	-0.009	-0.09	-0.14*	-0.08	0.22***	0.25***	-0.009	1	**-0.64*****
YH	0.40***	-0.16*	0.09	-0.03	0.10*	0.25***	0.23***	0.003	-0.03	0.007	-0.76***	1

Key: EC= emergence count, NN= number of nodules, NW=nodule weight, DF=days to flowering, Chl=chlorophyll content, LDM= leave dry matter, SDM= stem dry matter, PDM=pod dry matter, 100SW=weight of hundred seeds, HI=Harvest index, YH=Yield per hectare, *P≤0.05, **P≤0.01, ***P≤0,001

4.2.6.2 Combined analysis across two water regimes on climber beans

The combined analysis of variance across two water regimes on climbing beans was carried out to determine the impact of water stress on different fertilizer treatment. The results showed that there was a highly significant effect of macronutrient and macro-micro nutrient combination at ($P < 0.001$) on days from planting to flowering, number of pods and seed yield per hectare (Table 4. 38). The macronutrient and micronutrient combination influenced plants on number of days to flowering and number of pods at (0.05 and <0.001) respectively (Table 4. 38).The variations accounted were significant and below 10% on those 3 traits. However, a highest variation was shown at 9.4% on number of pods per plant (Table 4.38).

Table 4.38: Combined analysis of variance for agronomic data measured from climber beans trials at Kandiani dam

Days to flowering				%explained	number of pods				%explained	Yield per hectare				%explained
Source	D.f	M.S	Fpr.		Source	D.f	M.S	Fpr.		Source	D.f	M.S	Fpr.	
W.r	1	2.727			W.r	1	93824			W.r	1	86036		
Mac	8	33.63	<0.001	6.61	Mac	8	164205	<0.001	9.4	Mac	8	298596	<0.001	6.01
error a	40	5.091			error a	40	156772			error a	40	49681		
Mic	3	2.012	0.657	0.54	Mic	3	99809	0.05	3.4	Mic	3	17071	0.496	0.8
mac X mic	24	5.943	0.05	1.59	mac X mic	24	75710	<0.001	6.7	mac X mic	24	27675	0.177	1.3
error b	135	3.743			error b	135	78097			error b	135	21325		
Total	215				Total	215				Total	215			

Key: Key: D.f- degree of freedom; M.S- mean square, Fpr- F probability, % explained- percentage variation explained from sum of squares, Wr-water regime, Mac- macronutrients, Mic- micronutrients

4.3 Relationship between drought susceptibility index (DSI), drought tolerance efficiency (DTE) and grain yield as affected by macronutrients and micronutrients in two beans varieties at Kandiyani experiment

The results (Tables4. 39 and 4. 40) are showing high variability on yield performance and stability among 36 fertilizer treatments in two bean types under drought stress. Among thirty six treatments on bush beans, NP + Mo treatment showed maximum yield level (830 kg/ha) under moisture stress. However, under normal water supply NPK + Mo treatment had performed well with 2100 kg/ha of seed yield. Yield change after the water was withhold soon after flowering ranged from 2% on treatments supplied with phosphorus and boron (P + B) to 91% on treatments applied with Calcium extra-cal only (Ca). The least and highest drought susceptibility index (DSI), was observed on NPK + Mo and Ca + ZnS treatments. In addition, highest drought tolerance efficiency (DTE)was observed on P fertilizer treatments, while minimum reduction on seed yield was observed on P + B, NPRz + B, Ca + ZnS and NP + ZnS treatments(Table 4.39).

Climber beans yield change ranged from 1% on N + B and N + ZnS treatments to 69% on Ca + B and Ca + Mo treatments. Maximum yield level under moisture stress (500Kgha^{-1}) as well as in normal water supply condition (1500 kg/ha) was observed on NPRz + Mo treatments. The least drought susceptibility index (DSI), was observed on Ca + ZnS treatment and was highest on NPRz + Mo treatment. Treatments supplied with NP and NPRz + B fertilizer were observed to have high drought tolerance efficiency (DTE). However, minimum reduction on seed yield was observed on (N + B, N + ZnS, NPRz + B and K + B) treatments (Table 4.40).

Table 4.39: Drought susceptibility index (DSI),yield change and drought on tolerance efficiency (DTE) for bush beans on variety on thirty six fertilizer treatments in two soil moisture well watered (ww) and water stressed (ws) at Kandiyani dam.

Treatments	Yield (Kg-1)		Yield change	DTE	DSI
	WW	DS	(%)	(%)	(%)
NPRz	900	671	25	75	1.5
NPRz+B	704	682	25	97	1.1
NPRz+Mo	1100	676	3	61	1.8
NPRz+ZnS	1000	480	39	48	1.6
P	750	733	52	98	1.2
P+B	680	580	2	85	1.1
P+Mo	1000	647	15	65	1.6
P+Zns	778	315	35	40	1.3
NPK	1500	707	60	47	2.4
NPK+B	950	742	53	78	1.5
NPK+Mo	2100	689	22	33	3.4
NPK+ZnS	856	800	67	93	1.4
0	500	75	7	15	0.8
B	602	75	85	12	1.0
Mo	676	500	88	74	1.1
ZnS	576	420	26	73	0.9
N	691	86	27	12	1.1
N+B	676	324	88	48	1.1
N+Mo	671	290	52	43	1.1
N+ZnS	698	506	57	72	1.1
K	758	488	28	64	1.2
K+B	647	468	36	72	1.0
K+Mo	947	564	28	60	1.5
K+ZnS	704	275	40	39	1.1
Rz	940	664	61	71	1.5
Rz+B	884	760	29	86	1.4
Rz+Mo	884	577	14	65	1.4
Rz+ZnS	873	81	35	9	1.4
Ca	387	102	91	26	0.6
Ca+B	333	316	74	95	0.5
Ca+Mo	344	322	5	94	0.6
Ca+Zns	275	249	6	91	0.4
NP	813	404	9	50	1.5
NP+B	851	700	50	82	1.4
NP+Mo	880	830	18	94	1.4
NP+ZnS	836	102	6	12	1.4
GM	799	469			
CV	19.6	22			

Key:GM= grand mean, CV= coefficient of variance, WW= well watered, DS= drought stress

Table 40: Drought susceptibility index (DSI), yield change and drought tolerance efficiency (DTE)for climber beans variety on thirty six fertilizer treatments in two soil moisture well watered (ww) and water stressed (ws) at Kandiyani dam.

	Yield (Kg/ha)		Yield change	DTE	DSI
Treatments	ww	Ds	(%)	(%)	(%)
NPRz	507	406	20	80	0.8
NPRz+B	524	513	2	98	0.8
NPRz+Mo	1500	566	62	38	2.4
NPRz+ZnS	742	504	32	68	1.2
P	731	373	49	51	1.2
P+B	513	289	44	56	0.8
P+Mo	711	477	33	67	1.2
P+Zns	647	393	39	61	1
NPK	833	529	36	44	1.3
NPK+B	660	458	31	69	1.1
NPK+Mo	1009	353	65	35	1.6
NPK+ZnS	757	496	34	66	1.2
0	449	338	25	75	0.7
B	633	471	26	74	1.1
Mo	631	500	21	79	1
ZnS	518	438	15	85	0.8
N	509	471	7	93	0.8
N+B	522	516	1	99	0.8
N+Mo	567	535	6	94	0.9
N+ZnS	504	500	1	10	8.1
K	511	326	36	64	0.8
K+B	549	524	5	95	0.9
K+Mo	524	402	23	77	0.8
K+ZnS	589	271	54	46	1
Rz	496	366	26	74	0.8
Rz+B	480	387	19	81	0.8
Rz+Mo	269	188	30	70	0.4
Rz+ZnS	511	482	6	94	0.8
Ca	311	131	58	42	0.5
Ca+B	424	133	69	31	0.7
Ca+Mo	322	101	69	31	0.5
Ca+Zns	216	104	52	48	0.3
NP	676	435	36	64	1.1
NP+B	580	335	42	58	0.9
NP+Mo	780	384	51	49	1.3
NP+ZnS	751	496	34	66	1.2
GM	596	394			
CV	3.9	35			

Key: GM= grand mean, CV= coefficient of variance, ww= well watered, DS= drought stress

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study revealed that inorganic fertilizer application is very important in legume production under different water conditions. Under rain fed conditions, macronutrients such as potassium, phosphorus and nitrogen and micronutrients such as molybdenum, boron, zinc and sulfur and Rhizobium inoculants either singly or combined can play an important role in beans production, depending on factors such as soil type, site location in terms of temperature and rain fall and presence of indigenous rhizobium in the soil. By looking at the parameters that were used in this study such as number and weight of nodules, biomass, number of pods and seed yield among others, macronutrients such as P, N, and Rz are very crucial in legume production. On the other hand, micronutrients such as molybdenum played an important role on increasing number of nodules, number of pods and respective seed yield. However, combined application of macronutrients and micronutrient (boron) is paramount to higher yields in bean production.

Similarly the application of macronutrient under different water regimes is also important in beans production as this was shown by the increase in the number of days to flowering and number of nodules per plant. Importantly, combined application of macronutrients and micronutrients increased number of pods, 100 seed weight, and yield per hectare and harvest index. Specifically the application of phosphorus, molybdenum and Rhizobium inoculant fertilizer increased the number of nodules, pods and subsequently seed yield for both bean varieties under rainfed, irrigated and drought stress conditions.

Although inorganic fertilizer application is very important, soil moisture is also an important factor in seed yield expression for both beans types as shown by the increased yield of well watered bush beans compared to the drought stressed beans. However, the situation under drought stress was compounded by the application of micronutrient fertilizers especially molybdenum either singly or in combined applications which showed significantly higher yield than other treatments.

Drought tolerant efficiency (DTE) also support that fertilizer application mitigates the effect of drought on bean production, phosphorus showed a high DTE and minimized bean yield reduction. Although P showed a higher drought tolerance, macronutrient fertilizer application in combination with other macronutrients or micronutrients is also an important factor to consider as this reduces the susceptibility of the crop plants to drought and at the same time results in a lower yield reduction. For instance, under climber beans variety, NP and NPRz were observed to be the best with high drought susceptibility index (DSI) among the 36 treatments. However, combination of N, B and Zn_2SO_4 treatments resulted in smaller percentage of yield reduction under drought conditions.

In conclusion, drought is one of the major limiting factors of bean production and the effect can be mitigated through fertilizer application.

5.2 Recommendations

1. The study should be repeated under farmer's conditions across different agro ecological zones as this may give an insight into the specific fertilizer requirements per agro ecological zone.

2. Is there a need to make similar studies using P, rhizobium inoculant and Mo in different rates under different level of soil moisture in both beans type (climber and bush), this should be done to help to coming up with specific rate of fertilizers for good DTE, DSI and minimum yield reduction.

3. The study also recommends the use of P and Mo fertilizer for good yield and yield stability in common beans production under drought condition.

6.0 REFERENCES

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