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Effect of Mineral Nitrogen and Legume Intercrops on Maize (*Zea Mays* L.) Nitrogen Uptake, Nutrient Use Efficiency and Yields in Chitedze and Zomba, Malawi

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Abstract

Nitrogen (N) is the most critical plant nutrient. Maize has a high nitrogen demand. Low maize (*Zea mays* L.), yields in smallholder farms of Malawi, the country's staple, is attributable to declining N fertility aggravated by the ever increasing price of fertilizer. Little effort has been made to establish the best nitrogen rate in a maize-cowpea and maize-bean intercrop under variable soil conditions as a way of improving production, and was the objective of the current study. Field experiments were conducted at Chitedze Agricultural Research Station in Lilongwe and Makoka Agricultural Research Station in Zomba during the 2016/17 growing season. A split plot layout in a randomized complete block design, with three replicates was used. The main plots were; sole maize, sole bean, sole cowpea, bean/maize and cowpea/maize intercrop systems. The sub plots were N fertilizer rates (0, 52.5, 78.75 and 105 kg N ha⁻¹), applied as urea. The data collected was subjected to analysis of variance using SAS software version 9.3 (SAS Institute Inc.) at P<0.05. Means were separated using Duncan Multiple Range (DMRT) test at 95% significance level. The results showed that application of N increased maize N uptake and grain yield. NUE however decreased with increasing N fertilizer rate.

Keywords: common beans, cowpea, urea

1. Introduction

Nitrogen (N) is a critical component of organic molecules such as amino acids, proteins and nucleic acids (Walworth, 2013) and promotes vigorous vegetative growth (Havlin, Tisdale, Beaton, & Werner, 2008; Paul, 2008). It is the most frequently deficient plant nutrient in Malawian soils. This has resulted into low maize (*Zea mays* L.) yields, the country's staple (Munthali & Mazuma, 2010). The deficiency of N in soil is as a result of continuous cropping without adequate replenishment of nutrients lost through harvesting. Nitrogen (N) is one of the essential nutrients affected by increased soil cropping (Gachene & Kimaru, 2003; Mbewe, 2011). Alternative ways of improving nitrogen fertility of soil and subsequently increase maize yield should be identified.

Studies conducted on legumes have reported that legumes have the potential to significantly contribute to soil nitrogen, through biological nitrogen fixation, and increase yields of either subsequent or associated non-nodulating crops such as cereals through biological nitrogen fixation (Hayat, Safdar, Siddique, & Chatha, 2008).

Cowpea (*Vigna unguiculata* L) is a legume of African origin and one of the most ancient crops ever domesticated by man. It is an important source of food and income (Food and Agriculture Organisation [FAO], 2004). Africa produces 96% of the more than 5.4 million tons of the global cowpea production. Cowpea is highly adaptable to grow in different soil types and intercropping systems. It also has the following advantages; it is drought resistant and has the ability to improve soil fertility through biological nitrogen fixation and also reduces the risk of soil erosion (International Institute of Tropical Agriculture [IITA], 2016). In Malawi cowpea is an important legume crop for small holder farmers and the crop is adapted to grow in a wide range of local conditions (Nkongolo, Bokosi, Malusi, Vokhiwa, & Mphepo, 2009). The production of cowpea in Malawi is estimated to be 50 249 million tons on average between the years 2000 to 2013 (FAOSTAT, 2013).

Common bean (*Phaseolus vulgaris* L) is the most important food legume for direct consumption in the world and it is a major source of dietary protein in Malawi. It is also an important cash crop for smallholder farmers in Malawi (FAO, 1999; Magreta & Jambo, 2012). International Crops Research Institute for the Semi-Arid Tropics [ICRISAT] (2013) estimated the production of beans in Malawi to be about 111 889 million tones on average between 2000- 2011. There is a gap in information on the best nitrogen rate in a maize- cowpea and maize-bean intercrop under variable soil conditions as a way of improving production.

The current study investigated the effect of legume intercrops and mineral nitrogen on nutrient uptake, nutrient use efficiency and grain yield of maize (*Zea mays* L.) in Malawi.

2. Method

2.1 Site

Field experiments were conducted in two sites in 2016/17 growing season. The first site was the Chitedze Agricultural Research Station, near Lilongwe in the Central part of Malawi. It is located at about 13° 59'S longitude and 33° 38' E latitude at an elevation of 1146 m asl. Chitedze research station has a mean annual temperature of 20°C and receives an average annual rainfall of 800 to 900 mm, 85% of which falls from November to April. The station is a representative of Lilongwe plain, which is a major maize producing agro-ecology of the country. The terrain is flat to gently undulating. The soils are chromic Luvisols. They have a well-developed structure with a dark, reddish brown top soil. The pH ranges from 4.5 to 6.0.

The second site was Makoka Agricultural Research Station near Zomba, in the southern region of Malawi. The soil is classified as a Ferric Lixisol (FAO/UNESCO) or Oxid Hapleustalf (USDA). It is situated at about 15° 30'S longitude and 35° 15'E latitude at an elevation of 1030m above sea level. The soil texture is 46% sand, 46% clay and 8% silt. Total annual rainfall ranges from 560 to 1600 mm, with a mean of 1024 mm. The site experiences unimodal type of rainfall with most of the rains falling from November to April.

Chemical and physical characteristics of soils at Chitedze and Makoka Agricultural research stations are shown in Table 1.

Table 1. Initial physical and chemical characteristics of soils at Chitedze and Makoka Agricultural Research Stations

Property	Units	Chitedze		Makoka	
		Value	Interpretation*	Value	Interpretation*
PH	-	6.09	Medium	4.91	Deficient in Ca
Organic Carbon	%	1.58	Medium	0.32	Low
Organic Matter	%	2.75	Adequate	0.53	Low
Total N	%	0.20	Medium	0.10	Low
Available P	ppm	39.54	High	72.98	High
K	cmol _c kg ⁻¹	0.11	Low	0.11	Low
Ca	cmol _c kg ⁻¹	0.45	Low	0.16	Low
Mg	cmol _c kg ⁻¹	0.05	Low	0.04	Low
Zn	ppm	0.31	Low	0.10	Low
Clay	%	19.20		19.33	
Silt	%	13.00		6.83	
Sand	%	67.80		73.84	
Textural class		Sandy clay loam		Sandy clay loam	

*Chemical characteristics of soil were classified according to Landon (1991)

2.2 Treatments and Experimental Design

A split plot layout in a randomized complete block design (RCBD), with three replications, was used. The main plots were; cropping systems (sole maize, sole bean, sole cowpea, bean/maize and cowpea/maize intercrops). The sub plots were four rates of N (0, 52.5, 78.75 and 105 kg N ha⁻¹), applied as urea fertilizer. The inorganic fertilizer rates correspond to zero, one-half (50%), 75 % and 100% of the recommended national fertilizer rate for maize in Malawi. The recommended rate for Malawi is 105 kg N ha⁻¹ by side dressing (MAIFS, 2004). The sub plot sizes measured 1m × 7.5 m. Space for foot path (0.5 m) between plots and blocks (1 m), was provided.

2.3 Land Preparation and Planting

Land was prepared manually using hand implements. Maize was planted at spacing of 75cm between rows and

25 cm between planting stations. Two seeds were planted per hill and later thinned to 1 seedling, when plants were 10cm tall (53,000 plants/ha). The maize variety SC 403 was planted. In the intercropping system, the legume seeds were sown between two maize rows, at spacing of 75 cm between rows and 25 cm between planting stations. Two seeds were planted per station, and then thinned to one plant. A medium duration common bean variety (Mwaiwathu alimi) was planted. The cowpea variety planted was IT82E-16. Sole legumes were sown at a spacing of 75 cm between rows and 25 cm between planting stations.

2.4 Fertilizer Application and Field Management

Urea fertilizer was applied as a source of nitrogen, in two equal splits; 7 and 30 days after planting, to minimize potential leaching losses. Triple superphosphate (TSP) was applied at a rate of 40 kg P ha⁻¹ as basal dressing fertilizer. Careful and superficial manual weeding was done three times, after crop emergence. Pesticides (Dimethoate and Cypermethrin) were applied twice. The first application was done when the plants were two weeks old and the second when the maize was tasseling and the legumes were flowering. The pesticides were applied at a rate of 3litres/hectare.

2.5 Soil and Plant Sampling

Soil samples were collected using Edelman soil augers (0-30 cm) from experimental fields using traverse method, before application of treatments, and then composited. Thereafter top soil samples (0-30 cm) were collected at harvest of maize, randomly from three locations in each plot between planting stations within a row, and composited.

Maize plant samples were collected at 50 % tasseling stage. The leaf opposite the ear was taken from five plants per plot. The plants were selected randomly from the plot border rows. At physiological maturity the above ground portion of the maize was harvested from two internal rows. Maize samples were divided into stover (stalk and leaves), cob and grains. For legumes at harvest, samples were collected from two internal rows and divided into stover and pods.

2.6 Soil and Plant Analysis

Soil samples were air dried to constant weight, for at least 96 hours, ground to pass through a 2mm sieve and analyzed for organic N, C, extractable P and exchangeable Ca, Mg and K, following standard procedures stipulated by Anderson and Ingram (1993). Exchangeable cations were determined by using 1N ammonium acetate. Soil pH was read in a suspension of 1:2.5 soils: distilled water. Texture was determined using a hydrometer in a dispersant solution of 3% sodium hexametaphosphate (Anderson & Ingram, 1993).

Plant samples collected (maize and legumes) were weighed and chopped into small pieces. Sub-samples oven dried at 65°C for 72 hours. The weights of the oven dry sub-samples were recorded. The dried maize samples were ground and digested in sulphuric acid- selenium extractant and analyzed for total nitrogen according to standard procedures stipulated by Anderson and Ingram (1993).

2.7 Calculation Procedures

Maize nutrient uptake: was calculated from nutrient concentrations and dry matter measured using the following formulae (Peterburgski, 1986);

$$\text{Total nutrient uptake} = \text{nutrient concentration} \times \text{dry matter yield} \quad (1)$$

Maize and legume Yield: Grain yield was expressed at 13% moisture content, determined by moisture meter. The weight of grains and dry matter were measured by an analytical balance and yield converted into kg ha⁻¹ using the following formulae:

$$\text{Yield (kg/ha)} = \text{yield (kg)/m}^2 \text{ (kg)} \times 10000 \quad (2)$$

Nutrient use efficiency: using treatment yield (NUE) was calculated using the following formula (Brentrup & Palliere, 2010):

$$\text{NUE} = \frac{\text{yield with nitrogen} - \text{yield without nitrogen}}{\text{total nitrogen added}} \quad (3)$$

2.8 Statistical Analysis

Data was subjected to analysis of variance (ANOVA) conducted using statistical package SAS version 9.3. The treatment means were separated using Duncan's Multiple Range Test (DMRT) tests at P<0.05.

3. Results

3.1 Effect of Cropping System, Nitrogen Level, Location and Their Interaction on Maize Grain Yield

The main effects of nitrogen levels and locations on maize grain yield were significant (Table 2). Significantly

higher values ($P < 0.05$) were obtained with application of 105 kg N ha^{-1} (N3), followed by $78.75 \text{ kg N ha}^{-1}$ (N2), N1 ($52.5 \text{ kg N ha}^{-1}$) and N0 (0 kg N ha^{-1}), in that order. Maize grain yield was significantly higher at Chitedze than at Makoka. Effect of cropping system was not significant for maize grain yield. The effect of interaction of cropping systems x levels of nitrogen was not significant for maize grain yield (Table 3). The nitrogen levels x cropping systems x location interactions effects were not significant ($P < 0.05$) for maize yield grain yield (Table 4). The interactive effects of cropping system x location and nitrogen levels x location maize grain yield were not significant (Table 5).

Table 2. Effect of nitrogen level, cropping system and location on maize grain yield, DM yield and weight of cobs

Treatment	Maize grain Yield(Mt/ha)
Nitrogen Level	
N3	6.25a
N2	5.37b
N1	3.99c
N0	1.54d
Cropping system	
Maize- monocropping	4.47a
bean/maize- intercropping	4.16a
cowpea/maize- intercropping	4.23a
Location	
Chitedze	5.04a
Makoka	3.54b

Means with the same letter are not significantly different ($P < 0.05$) according to Duncan test

Key: N0 = 0 kg N ha^{-1} , N1 = $52.5 \text{ kg N ha}^{-1}$, N2 = $78.75 \text{ kg N ha}^{-1}$, N3 = 105 kg N ha^{-1}

Table 3. Effect of the interaction between cropping systems and levels of nitrogen on maize grain yield (means \pm std. error)

Cropping system	Nitrogen level	Maize grain yield (Mt/ha)
maize monocropping	N0	1.77 ± 0.36
	N1	4.49 ± 0.54
	N2	5.62 ± 0.90
	N3	6.02 ± 0.35
bean/maize intercropping	N0	1.27 ± 0.41
	N1	3.53 ± 0.92
	N2	5.84 ± 0.51
	N3	6.03 ± 0.81
cowpea/maize intercropping	N0	1.59 ± 0.50
	N1	3.95 ± 0.41
	N2	4.67 ± 0.44
	N3	6.71 ± 0.33

Key: N0 = 0 kg N ha^{-1} , N1 = $52.5 \text{ kg N ha}^{-1}$, N2 = $78.75 \text{ kg N ha}^{-1}$, N3 = 105 kg N ha^{-1}

Table 4. Effect of interaction between cropping system x nitrogen level x location on maize yield (means \pm std. error)

Cropping system	Nitrogen level	Location	Maize Yield (Mt/ha)
maize monocropping			
	N0	Chitedze	2.24 \pm 0.48
		Makoka	1.30 \pm 0.43
	N1	Chitedze	5.41 \pm 0.61
		Makoka	3.57 \pm 0.46
	N2	Chitedze	7.10 \pm 1.00
		Makoka	4.14 \pm 0.95
	N3	Chitedze	6.03 \pm 0.77
		Makoka	6.00 \pm 0.14
bean/maize intercropping			
	N0	Chitedze	2.01 \pm 0.35
		Makoka	0.52 \pm 0.42
	N1	Chitedze	4.97 \pm 1.37
		Makoka	2.10 \pm 0.55
	N2	Chitedze	6.90 \pm 0.12
		Makoka	4.77 \pm 0.40
	N3	Chitedze	7.03 \pm 0.93
		Makoka	5.03 \pm 1.18
cowpea/maize intercropping			
	N0	Chitedze	1.82 \pm 0.71
		Makoka	1.35 \pm 0.85
	N1	Chitedze	4.44 \pm 0.70
		Makoka	3.46 \pm 0.31
	N2	Chitedze	5.17 \pm 0.83
		Makoka	4.16 \pm 0.21
	N3	Chitedze	7.38 \pm 0.25
		Makoka	6.05 \pm 0.13

Key N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹.

Table 5. Effect of the interactions between cropping systems and location, nitrogen levels and location on maize yield (means \pm std. error)

Treatment	Location	Maize grain yield (Mt/ha)
Cropping system		
maize monocropping		
	Chitedze	5.19 \pm 0.63
	Makoka	3.75 \pm 0.56
bean/maize intercropping		
	Chitedze	5.23 \pm 0.71
	Makoka	3.11 \pm 0.64
cowpea/maize intercropping		
	Chitedze	4.71 \pm 0.66
	Makoka	3.75 \pm 0.54
Nitrogen level		
N0	Chitedze	2.02 \pm 0.27
	Makoka	1.06 \pm 0.33
N1	Chitedze	4.94 \pm 0.50
	Makoka	3.04 \pm 0.33
N2	Chitedze	6.39 \pm 0.48
	Makoka	4.35 \pm 0.32
N3	Chitedze	6.82 \pm 0.41
	Makoka	5.69 \pm 0.38

Key N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹

3.2 Effect of Cropping System, Nitrogen Level, Location and Their Interaction on Nitrogen Uptake by Maize

There were significant ($P < 0.05$) main effects of nitrogen levels and location on N uptake by maize. The highest uptake was observed in N3 (105 kg N ha^{-1}) nitrogen level, followed by N2 ($78.75 \text{ kg N ha}^{-1}$). The lowest amounts of nutrient uptake were recorded in N0 (0 kg N ha^{-1}) and N1 ($52.5 \text{ kg N ha}^{-1}$) nitrogen levels. Significantly higher uptake was observed at Chitedze than Makoka. Cropping systems did not have any significant effect on nutrient uptake (Table 6). The interactive effect of cropping systems x nitrogen levels on N uptake by maize was significant ($P < 0.05$) (Table 7). The uptake was significantly higher in bean/maize intercropping system followed by cowpea/maize intercropping under N3 level of nitrogen in both cropping systems and in maize monocropping when the nitrogen levels were N1 and N2.

The effect of cropping systems x location interaction on N uptake in maize was significant only under maize monocropping system. The uptake was significantly higher at Chitedze than at Makoka in maize monocropping system at both sites (Table 8). The interaction of nitrogen levels x location on N uptake by maize was not significant ($P < 0.05$). The interaction effects of nitrogen level x cropping system x location on N uptake by maize was significant ($P < 0.05$) (Table 9). Uptake was significantly higher under maize monocropping system combined with N3 level of nitrogen at Chitedze. The values were significantly lower under cowpea/maize intercropping system combined with N0 level of nitrogen at Makoka.

Table 6. Effects of cropping systems, nitrogen levels and locations on nutrient uptake in maize

Treatments	Nutrient uptake (mg-N/plant)
Cropping system	
maize monocropping	132.13a
bean/maize intercropping	117.92a
cowpea/maize intercropping	122.68a
Nitrogen level	
N0	56.05c
N1	103.36bc
N2	139.41b
N3	198.15a
Location	
Chitedze	163.03a
Makoka	85.45b

Means with the same letter within a column are not significantly different ($P < 0.05$) according to Duncan test

Key: N0 = 0 kg N ha^{-1} , N1 = $52.5 \text{ kg N ha}^{-1}$, N2 = $78.75 \text{ kg N ha}^{-1}$, N3 = 105 kg N ha^{-1} .

Table 7. Effect of interaction between nitrogen levels x cropping system on nutrient uptake in maize (means \pm std. error)

Cropping system	Nitrogen level	Nutrient uptake (mg-N/plant)
maize monocropping	N0	53.07 \pm 10.53
	N1	123.49 \pm 25.02
	N2	132.39 \pm 16.65
	N3	219.57 \pm 38.86
bean/maize intercropping	N0	49.66 \pm 16.30
	N1	79.94 \pm 19.24
	N2	154.56 \pm 49.26
	N3	187.49 \pm 44.08
cowpea/maize intercropping	N0	65.42 \pm 25.32
	N1	106.65 \pm 41.92
	N2	131.28 \pm 39.25
	N3	187.38 \pm 55.81

Key: N0 = 0 kg N ha^{-1} , N1 = $52.5 \text{ kg N ha}^{-1}$, N2 = $78.75 \text{ kg N ha}^{-1}$, N3 = 105 kg N ha^{-1} .

Table 8. Effects of cropping system x location, nitrogen levels x location on nutrient uptake in maize (means \pm std. error)

Treatments	Location	Nutrient uptake (mg N/plant)
Cropping System		
maize monocropping	Chitedze	151.85 \pm 28.00
	Makoka	112.41 \pm 18.82
bean/maize intercropping	Chitedze	156.23 \pm 35.27
	Makoka	79.60 \pm 13.61
cowpea/maize intercropping	Chitedze	181.02 \pm 35.21
	Makoka	64.34 \pm 9.95
Nitrogen Levels		
N0	Chitedze	75.35 \pm 16.39
	Makoka	36.75 \pm 8.59
N1	Chitedze	136.63 \pm 27.61
	Makoka	70.09 \pm 13.72
N2	Chitedze	180.17 \pm 34.55
	Makoka	98.65 \pm 13.72
N3	Chitedze	259.98 \pm 39.85
	Makoka	136.31 \pm 15.81

Key: N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹.

Table 9. Effect of the interaction between nitrogen levels x cropping system x location on nutrient uptake in maize (means \pm std. error)

Cropping System	Nitrogen levels	Location	Nutrient uptake (mg N/plant)
maize monocropping	N0	Chitedze	64.98 \pm 8.73
		Makoka	41.15 \pm 18.33
	N1	Chitedze	147.37 \pm 39.42
		Makoka	99.62 \pm 31.73
	N2	Chitedze	136.78 \pm 29.40
		Makoka	128.00 \pm 22.43
	N3	Chitedze	258.27 \pm 72.06
		Makoka	180.86 \pm 29.32
bean/maize intercropping	N0	Chitedze	59.12 \pm 31.09
		Makoka	40.20 \pm 16.51
	N1	Chitedze	97.79 \pm 37.84
		Makoka	62.10 \pm 10.02
	N2	Chitedze	223.72 \pm 79.01
		Makoka	85.40 \pm 33.23
	N3	Chitedze	244.27 \pm 78.38
		Makoka	130.71 \pm 18.60
cowpea/maize intercropping	N0	Chitedze	101.94 \pm 40.52
		Makoka	28.91 \pm 15.18
	N1	Chitedze	164.75 \pm 70.40
		Makoka	48.55 \pm 21.28
	N2	Chitedze	179.99 \pm 72.97
		Makoka	82.56 \pm 1.71
	N3	Chitedze	277.41 \pm 86.27
		Makoka	97.35 \pm 5.18

Key: N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹

3.3 Nutrient Use Efficiency (NUE) of Maize

The results in table 10 indicate that N2 (78.75 kg N ha⁻¹) had the highest nitrogen use efficiency followed by N1

(52.5 kg N ha⁻¹) and N3 (105 kg N ha⁻¹) in that order.

Table 10. Nutrient Use Efficiency of maize at different nitrogen levels

Nitrogen level	Maize yield(Mt/ha)	NUE (%)
N0	1.54	
N1	3.99	46.67
N2	5.37	48.63
N3	6.25	44.86

3.4 Effect of Cropping System, Nitrogen Level, Location and Their Interaction on Legume Biomass and Number of Nodules

The main effect cropping systems on legume DM yield and number of nodules was significant ($P < 0.05$). The results in table 11 indicate that significantly higher values of legume DM yield were obtained under sole cowpea while significantly higher values of number of nodules were recorded under sole bean and bean/maize intercropping. On the other hand significantly lower values of legume DM yield were recorded under bean/maize intercropping system while significantly lower values of number of nodules were recorded under sole cowpea. From the same table the main effect of location was significant ($P < 0.05$) for DM yield, and number of nodules. Significantly higher number of nodules was reported at Chitedze. On the other hand significantly higher values of DM yield were recorded under Makoka.

The interactive effect of cropping systems x levels of nitrogen was significant ($P < 0.05$) on legume DM yield and number of nodules (Table 12). Significantly higher values were obtained under the following treatment combinations: cowpea/maize intercropping x N3 and bean/maize intercropping x N1, respectively. On the other hand significantly lower values were obtained under the following treatment combinations; bean/maize intercropping system x N2 and cowpea/maize intercropping x N2 for legume DM and number of legumes, respectively (Table 13).

The effect of interaction of cropping system x nitrogen level x location was significant ($P < 0.05$) on legume dry matter (Table 14). From the same table it was observed that the interaction was significant under cowpea/maize intercropping and it was not significant under bean/maize intercropping system. The interactions that produced significantly higher values of legume DM and number of nodules were observed under the following treatment combinations; cowpea/maize intercropping x N3 x Makoka, and cowpea/maize intercropping x N3 x Chitedze.

The effect of the interaction of cropping system x location was significant for legume DM yield (Table 15). The results indicated that significantly higher values of legume yield DM yield were obtained under the treatment combination of sole cowpea x Makoka. From the same table significantly higher values for number of nodules were obtained under the following treatment combinations; cowpea/maize intercropping x Chitedze. The interaction of nitrogen levels x location was significant for legume yield DM yield (Table 15). Significantly higher values were obtained under the following treatment combinations; N3 level of nitrogen x Makoka.

Table 11. Effect of Nitrogen level, cropping system and location on legume dry matter (DM) yield and number of nodules

Treatments	Legume DM yield (Mt/ha)	Number of nodules/plant
Nitrogen Level		
N0	1.00a	14.58a
N1	1.05a	12.08a
N3	1.16a	13.75a
N2	0.93a	9.08a
Cropping system		
Sole cowpea	2.66a	5.66c
Sole bean	1.75b	26.33a
cowpea/maize intercropping	1.26c	7.33bc
bean/maize intercropping	0.81d	17.41ab
Location		
Chitedze	0.98b	19.40a
Makoka	1.56a	6.80b

Means with the same letter within a column are not significantly different ($P < 0.05$) according to Duncan test

Key: N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹.

Table 12. Effect of the interaction of cropping systems x levels of nitrogen on legume DM yield, and number of nodules (means \pm std. error)

Cropping System	Nitrogen Level	DM Yield(Mt/ha)	Number of Nodules/plant
bean/maize intercropping	N0	0.83 \pm 0.08	18.83 \pm 6.54
	N1	0.87 \pm 0.17	19.00 \pm 6.10
	N2	0.65 \pm 0.09	13.67 \pm 2.74
	N3	0.88 \pm 0.16	18.17 \pm 10.84
cowpea/maize intercropping			10.33 \pm 1.36
	N0	1.17 \pm 0.24	
	N1	1.4 \pm 0.22	5.17 \pm 0.65
	N2	1.21 \pm 0.31	4.50 \pm 0.89
	N3	1.45 \pm 0.29	9.33 \pm 5.94

N0 = 0 kg N ha⁻¹, **N1** = 52.5 kg N ha⁻¹, **N2** = 78.75 kg N ha⁻¹, **N3** = 105 kg N ha⁻¹

Table 13. Effect of interaction of cropping system x nitrogen level x location on legume DM yield, and number of nodules (means \pm std. error)

Cropping System	Nitrogen Level	Location	DM (Mt/ha)	Number of nodules/plant
bean/maize intercropping	N0	Chitedze	0.94 \pm 0.04	31.00 \pm 7.94
		Makoka	0.72 \pm 0.13	6.67 \pm 1.67
	N1	Chitedze	0.86 \pm 0.15	32.00 \pm 4.04
		Makoka	0.88 \pm 0.34	6.00 \pm 1.00
	N2	Chitedze	0.76 \pm 0.09	19.67 \pm 0.88
		Makoka	0.55 \pm 0.15	7.67 \pm 0.88
	N3	Chitedze	0.83 \pm 0.19	31.33 \pm 20.34
		Makoka	0.94 \pm 0.31	5.00 \pm 0.58
cowpea/ maize intercropping	N0	Chitedze	0.89 \pm 0.23	10.33 \pm 1.86
		Makoka	1.44 \pm 0.41	10.33 \pm 2.40
	N1	Chitedze	0.85 \pm 0.19	5.00 \pm 1.15
		Makoka	1.62 \pm 0.26	5.33 \pm 0.88
	N2	Chitedze	0.66 \pm 0.06	3.33 \pm 0.67
		Makoka	1.75 \pm 0.44	5.67 \pm 1.45
	N3	Chitedze	1.10 \pm 0.15	14.67 \pm 12.17
		Makoka	1.79 \pm 0.53	4.00 \pm 0.00

Key: N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹

Table 14. Effect of the interactions between cropping systems and location, nitrogen levels and location on legume DM yield, and number of nodules (means \pm std. error)

Treatments	Location	DM (Mt/ha)	Number of Nodules/plant
Cropping System			
bean/maize intercropping	Chitedze	0.84 \pm 0.06	28.50 \pm 4.98
	Makoka	0.77 \pm 0.12	6.33 \pm 0.56
cowpea/maize intercropping	Chitedze	0.88 \pm 0.09	8.33 \pm 2.97
	Makoka	1.65 \pm 0.18	6.33 \pm 0.96
cowpea monocropping	Chitedze	1.84 \pm 0.39	5.67 \pm 3.18
	Makoka	3.47 \pm 1.00	5.67 \pm 1.76
bean monocropping	Chitedze	1.11 \pm 0.08	41.00 \pm 13.89
	Makoka	2.39 \pm 0.83	11.67 \pm 2.40
Nitrogen level			
N0	Chitedze	0.92 \pm 0.11	20.67 \pm 5.89
	Makoka	1.08 \pm 0.25	8.50 \pm 1.54
N1	Chitedze	0.86 \pm 0.15	18.50 \pm 6.32
	Makoka	1.25 \pm 0.25	5.67 \pm 0.61
N2	Chitedze	0.71 \pm 0.05	11.50 \pm 3.69
	Makoka	1.15 \pm 0.34	6.67 \pm 0.88
N3	Chitedze	0.97 \pm 0.18	23.00 \pm 11.24
	Makoka	1.36 \pm 0.33	4.50 \pm 0.34

Key: N0 = 0 kg N ha⁻¹, N1 = 52.5 kg N ha⁻¹, N2 = 78.75 kg N ha⁻¹, N3 = 105 kg N ha⁻¹

4. Discussion

4.1 Main Effects of Cropping System, Nitrogen Level, Location on Maize Grain Yield

N fertilizer application (52.5, 78.75 and 105 kg N ha⁻¹) resulted in significant increases in maize grain yield compared to control (no fertilizer). Nitrogen is a critical macronutrient for the growth of maize and its application enhances vigorous vegetative growth (Havlin *et al.*, 2008). Many authors including Sebetha (2015), Abayomi, George-Arijenja and Kolawole (2006), Mahdi and David (2005), Morgado and Willey (2003) and Muchow (1988), similarly reported that application of N fertilizer generally resulted in increases in maize grain yield. Significant increases in maize grain yields occurred with increase in N level, from 0 to 105 kg N ha⁻¹, an indication that application of 105 kg N ha⁻¹ was optimal for maximum yield per unit area. Elevated N concentration results to healthier plant growth (Legg, Stanford & Bennett, 1979; Meisinger, Bandel, Stanford, & Legg, 1985). The reduction in maize grain yield under maize without N fertilizer is in agreement with the findings of Ding *et al.*, (2005) and Lucas (1986).

Maize grain yields were not significantly increased by inclusion of bean and cowpea. Maize has a C4 carbon assimilation pathway and may have had a competitive edge over legumes, which are C3 plants (Kitonyo, Chemining'wa, & Muthomi, 2013; Sage & Zhu, 2011). In addition, maize was more competitive for soil nitrogen because its roots are distributed in both shallow and deeper layers (Carruthers *et al.*, 2000). This is in contrast to the root systems of legumes which are smaller and confined to the upper layers (Hauggaard-Nielsen, Ambus & Jensen, 2001). Contrarily, most studies report that intercropped systems yield more than maize monocropping due to the ability of intercropped legumes to fix most of their nitrogen from the atmosphere (Chabi-Olaye, Nolte, Schulthess, & Borgemeister, 2005; Hauggaard-Nielsen & Jensen, 2001). Common beans are, however, poor N fixers, in comparison to other legumes; hence they do not contribute significantly towards the N requirement by maize (Westermann, Kleinkopf, Porter, & Leggett, 1981, Bliss, 1993; Martinez-Romero, 2003). Mineral nitrogen may have reduced the rate of nitrogen fixation by cowpea in this study (Houwaard, 1979).

Results showed significantly higher maize grain yield at Chitedze than Makoka. This may be attributed to lower rainfall amounts and higher temperature at Makoka. The optimal temperature for warm season maize is 15–20 °C for planting and 20–30 °C for the regular growing season (Bird, Cornelius, & Keys, 1977). The

temperature range for Makoka during the growing season was 17.84- 28.06 °C (Table 1). The higher temperature led to higher rates of evapotranspiration and therefore increased competition for moisture (Ben-Asher, Garcia, Garcia, & Hoogenboom, 2008). Water forms an integral part of plant body and plays an important role in growth initiation, maintenance of developmental process of plant life and hence has pivotal function in crop production (Aslam *et al.*, 2012).

4.1.1 Interaction Effects of Cropping System, Nitrogen Level, Location on Maize Grain Yield

The interaction effect of cropping systems \times N level was not significant for maize grain yield. This may possibly have been due to inhibition of symbiotic nitrogen fixation by the legumes due the application of N fertilizer (Erker & Brick, 2014). This is in agreement with the findings of Omokanye, Kelleher, and McInnes, (2013) who reported that the interaction effect of cropping system \times nitrogen levels on maize grain yield was not significant. The results further indicated that maize grain yield was not significantly affected by the interaction of cropping system \times location because maize faced stiff competition for resources from legumes. These findings are contrary to the findings of Sebetha (2015) who reported that the interaction had a significant effect on maize DM yield.

The interaction effect of cropping system \times location \times nitrogen level on maize grain yield was not significant. These findings suggest that cropping system did not play a vital role in dry matter accumulation. This finding is not in agreement with Sebetha (2015), who reported the significance of the interaction on maize grain yield.

4.2 Main Effects of Cropping System, Nitrogen Level, and Location On Nitrogen Uptake By Maize

The results indicated that an increase in N uptake by maize occurred with increasing rates of N fertilizer applied. The maximum value (198.15 mg-N/plant) was recorded with the highest N fertilizer level (105 kg N ha⁻¹) while the lowest (56.05 mg-N/plant) at zero fertilizer rate. Rahman (2011) and Morgado and Willey (2003) similarly reported that N uptake by maize plant was influenced significantly by N fertilizer application rate. They reported lowest uptake in control (no N fertilizer) treatment. Chirnoceanu, Badea, Petcu, and Picu (1997) also documented that high levels of soil nitrogen had a significant positive influence on the nutrient uptake and translocation in leaves. Thus, the N content in maize plants increased in variation with high fertilizer rates.

The results of this study indicated that there were no significant differences in nutrient uptake by maize in the different cropping systems. Common bean being a poor N fixer did not supply enough N to be taken up by both the legume and the cereal crop involved. Application of nitrogen fertilizer might have hindered symbiotic nitrogen fixation by cowpea (Henson & Bliss, 1991; Erker & Brick, 2014). Contrarily, Eskandari and Ghanbari (2009) reported significantly greater nitrogen uptake in intercropping than sole maize. They reported that intercropping was more efficient at exploiting a larger soil total volume if component crops have different rooting habits, especially depth of rooting.

Nitrogen uptake by maize was significantly greater at Chitedze than at Makoka. This difference may be attributed to the differences in total soil N at the sites. The levels at Chitedze and Makoka were medium (0.20%) and low (0.10%), respectively (Table 2), according to the nutrient classification of Landon (1991).

4.2.1 Interaction Effects of Cropping System, Nitrogen Level, Location on Nitrogen Uptake by Maize

The effect of cropping system \times N level interaction on N uptake by maize was significant. Significantly higher N uptake by maize was observed in the bean/maize intercropping system than cowpea/maize intercropping under N3 level of N, in both cropping systems, and maize monocropping combined with nitrogen levels of N1 and N2. This might have been due to enhanced supply nitrogen from fertilizer. Additionally, there may have occurred greater exploitation of a larger soil total volume for nutrients and water due to different rooting habits of the component crops in an intercropping system.

The effect of cropping systems \times location interaction on N uptake in maize was significant only under maize monocropping system. The higher uptake in maize monocropping system at both sites was because the maize did not face competition for nutrients from legumes, as they were sole crops.

N uptake by maize was not significantly affected by the interaction of nitrogen levels \times location. It is possible that this finding might be influenced by the location conditions such as moisture, soil aeration, soil drainage and soil textures which have an impact on N-transport and N -transformation processes that limit N availability to crops or lead to losses such as through leaching.

The nitrogen level \times cropping system \times location interaction effect on N uptake by maize was significant. The higher uptake observed under combination of maize monocropping system, N3 level of nitrogen at Chitedze was because sole maize did not have any competition from legumes for resources such as nutrients. N uptake was significantly lower under cowpea/maize intercropping system combined with N0 level of nitrogen at Makoka

research station. It is possible that maize suffered stiff competition for resources from legumes.

4.3 Nutrient Use Efficiency (NUE) of Maize

Maximum maize NUE (48.63 kg/kg) was obtained at application rate of 78.75 kg N ha⁻¹ and the minimum value (44.86 kg/kg) was recorded at the highest N rate (105 kg N ha⁻¹). The decrease in NUE with increasing N fertilizer rate was because yield rises less than the N supply in soil and fertilizer (Lopez-Bellido & Lopez-Bellido (2001), Raun & Johnson (1999), Pierce & Rice (1988), Sowers, Pan, Miller, & Smith (1994) and Zhao *et al.*, (2006) also reported that high rates of N decreased NUE in cereals. The findings of Kanampiu, Raun and Johnson (1997) generally indicated decreases in NUE but increases grain protein content and N loss with increasing N fertilizer rate.

4.4 Main Effects of Cropping System, Nitrogen Level, Location on Legume DM Yield and Number of Nodules

The main effect of cropping system on legume DM yield, and number of nodules was significant. Higher values of legume DM yield were reported under sole cowpea (2.66 Mt/ha) and sole bean (1.75Mt/ha) while lower values were obtained under cowpea/maize intercropping (1.26Mt/ha) and bean/maize intercropping system (0.81Mt/ha). These findings might be attributed to the well-known idea that cereals take up nutrients, especially N, mainly during the vegetative growth stage and associated vigorous growth may cause shading of the legume and thereby reduce its growth during later growth stages resulting in low yielding ability (Banik *et al.*, 2006). These results are supported by the findings of Birteeb, Addah, Jakper, and Addo-Kwafo (2011) who reported significantly reduced legume DM yield of intercropped legumes.

The main effect of N level on legume DM yield and number of nodules was not significant. These findings may be attributed to the fact that application of mineral nitrogen reduces both nodulation and the rate of nitrogen fixation by legumes (Houwaard, 1979). These findings are in agreement with the findings of Bagayoko, Buekert, Lung, Bationo and Romheld (1996) who observed that cowpea DM yield was not influenced by N application. Legume number of nodules per plant were higher under N0 (0 kg N ha⁻¹) than 52.5, 78.75 and 105 kg N ha⁻¹, however, they were not significantly different from the parameters obtained under 0 kg N ha⁻¹. It was expected that legume DM yield, and number of nodules under N fertilizer application would be lower than the control since N fertilization has a negative effect of legume growth, development and yield.

Legume DM yield was significantly affected by location. Legume DM yield was higher at Makoka than at Chitedze. It was also observed that the number of nodules per legume plant was affected by the location of the study site. Legumes planted at Chitedze research station had significantly higher number of nodules per plant (19.40) than at Makoka (6.80). This may be attributed to different soil structure and climatic conditions of these two sites. On the other hand N fertilizer application has a well-established negative effect on nitrogen fixation of legume root nodules. It is also reported that with increasing doses of N there is a nearly linear decrease in the number of root nodule (Becker, Alazard, & Ottow, 1986) This finding concurs with what Sebetha (2015) observed. He reported that number of nodules per cowpea plant was affected by location. The effect of location on number of number nodules can be attributed to fluctuations in pH, nutrient availability, temperature, and water status, among other factors that greatly influence the growth, survival, and metabolic activity of nitrogen fixation bacteria and plants, and their ability to enter into symbiotic interactions (Werner & Newton, 2005). The results on the number of nodules per plant concur with the ranges reported by Bhuvaneswari, Lesniak, and Bauer (1998).

4.4.1 Interaction Effects of Cropping System, Nitrogen Level, Location on Legume DM Yield and Number of Nodules

Legume DM yields and number of nodules were significantly affected by the interaction effect of cropping systems × levels of nitrogen. Findings of the study agree with the study of Sebetha (2015) who reported that the interaction of nitrogen and location significantly affected the number of nodules per cowpea plant. In addition common beans are poor N fixers, in comparison to other legumes; hence they do not contribute significantly towards the N requirement by maize (Westermann *et al.*, 1981, Bliss, 1993; Martinez-Romero, 2003).

Significantly higher values were obtained under the following treatment combinations; cowpea/maize intercropping × N3, and bean/maize intercropping × N1, respectively. On the other hand significantly lower values were obtained under the following treatment combinations; bean/maize intercropping system × N2 and cowpea/maize intercropping × N2 for legume DM yield and number of nodules, respectively. This might be attributed to cowpea having a higher potential of fixing N from the atmosphere through biological nitrogen fixation than beans (Freitas, Sampaio, Santos, & Fernandes, 2010).

The interaction effect of cropping system × location was significant for legume DM yield. The results indicate

that significantly higher values of legume DM yield were obtained under the treatment combination of sole cowpea x Makoka. This might be attributed to good environmental factors present at Makoka such conducive as temperature, good moisture content and good soil structure which were conducive for the production of cowpeas. Legume DM yield was significantly affected by the interaction effect of nitrogen levels and location. These findings contributed to the significance of comparing cropping systems towards improvement of legume yields since such interaction effect on legume yield was not revealed during previous studies.

The interaction effect of cropping system x nitrogen level x location was significant on legume DM yield. The interaction was however significant for number of nodules per cowpea plant (cowpea/maize intercropping). This is in agreement with what was reported by Sebetha (2015) that the interaction significantly affected the number of nodules per cowpea plant.

5. Conclusions

Diminishing land sizes, due to the ever increasing human population, and continuous cultivation practices have led to declining soil fertility and maize yield in Malawi. The study to determine effects of mineral N fertilizer application and legume integration on maize nutrient uptake and yield, demonstrated that N absorption by maize occurred with application of the water soluble urea fertilizer. N uptake increased with increase in fertilizer rate. Higher values were obtained with the application of 105 kg N ha⁻¹. The integration of legumes did not have any significant effect on uptake. This may have been because N fixation was not optimal. Nodulation in cowpea and common bean, a major conduit for available nitrogen into the biosphere, was not significantly increased by N application. Additionally, common bean is a poor N fixer. The study further showed that the effect of cropping system x N level interaction on N uptake by maize was significant. Significantly higher values were recorded under cowpea/maize intercropping system and N3 nitrogen level (105 kg N ha⁻¹). It was observed that NUE decreased with increasing N fertilizer rate. The minimum value (44.86 kg/kg) was recorded at the highest N rate (105 kg N ha⁻¹). Most of the fertilizer remains unutilized leading to nutrient toxicity. On the other hand, there was a tremendous reduction in maize development and yield when no N fertilizer was applied to the maize. Cropping system did not have an effect on maize development and yield..

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