

Maximizing nitrogen and land use efficiencies of intercropped maize with cowpea after some preceded winter field crops

ABSTRACT

A field study was conducted in Mallawi Agricultural Experiments and Research Station, El-Minia governorate, Egypt to decrease mineral nitrogen (N) inputs of maize with increase farmers' benefit. Local maize variety T.W.C. 310 was grown under intercropping and sole cultures in one row/ridge that received three mineral N fertilizer rates (75.0, 87.5 and 100 % of the recommended N rate of maize), while local variety of cowpea seeds cream 1 were drilled in one row and two rows/ridge under intercropping and sole cultures. A split split plot design with three replicates was used. Maize grain yield and its attributes were increased after legume crops harvest compared to those grown after wheat harvest. Mixed pattern increased grain yields per plant and per ha by 4.00 and 1.94 %, respectively, in comparison with sole culture in addition to yielding 16.85 ton/ha of cowpea forage. There were no significant differences between 87.5 and 100% of mineral N fertilizer rates for all the studied traits. Cowpea improved N use efficiency (NUE) for intercropped maize under mixed stand. Land equivalent ratio (LER) and land equivalent coefficient (LEC) values for intercrops were much greater than 1.00 and 0.25, respectively, indicating less land requirements of intercropping systems than sole maize. Farmer's benefit was achieved by intercropping cowpea with maize that received 87.5% of the recommended mineral N fertilizer dose of maize after berseem cutting.

Keywords: Crop sequence, Intercropping, Maize, Cowpea, Mineral N fertilizer, NUE.

INTRODUCTION

Sustainable agriculture requires a compatible relationship among the intercrops, the atmosphere, and the soil especially in the presence the urgent need to maximize the efficient use of nitrogen (N) without excessive use of mineral N fertilizer. Reduction of applied N fertilizer rate to an optimized level can reduce soil nitrate leaching (**Power et al., 2000**). Large amount of fertilizer N loss to the environment could cause a serious environmental problem such as groundwater contamination (**Chen et al., 2004**). However, maize (*Zea mays* L.) plant development is strongly dependent on the availability of N in the soil and the efficiency of N utilization for biomass production and yield (**Sonnevald, 2012**). It is a strategic crop and it is used for human consumption, animal and poultry feeding and industrial purposes. Demand for the maize grains in the Egyptian market is intensively increasing where maize cultivated area reached about 814435 ha in 2013 with an average yield of 7.64 ton per ha (**Bulletin of Statistical Cost Production and Net Return, 2014**).

Certainly, maize provides high yield in terms of dry matter, but there is a shortage in green forage supply during the summer season. Additionally, the demand for mineral N fertilizers that required for maize growth and development has prompted to minimize the N - fertilizer rates, especially some of the major causes of low maize yield are declining soil fertility and insufficient use of fertilizers resulting in severe nutrient depletion of soils (**Buresh *et al.*, 1997**). Accordingly, intercropping a legume forage crop such as Cowpea (*Vigna unguiculata* L.) with maize is very important tool for minimize the mineral N - fertilizer rates and successful cattle feeding which is severely limited by marked seasonal feed deficits in the summer season; especially soil quality is estimated by observing or measuring several different properties or processes. Cowpea facilitates N uptake of the intercropping maize (**Shu - Min and Fan, 2011**) and consequently, N symbiotic fixation has contributed to facilitate N uptake for intercropped maize (**Latati *et al.*, 2013**). Cowpea is promising double purpose forage and seed crop for its green canopy or using it in animal diets as dry seeds, as well as, it is a primary source of plant protein for humans and animals (**HamdAlla *et al.*, 2014**) in the summer season.

Although, crop productivity per unit area can be enhanced by N fertilization and diverse/complex cropping sequences, however, these practices may strongly interact and impact soil properties differently (**Russell *et al.*, 2006**). These observations led to integration of crop sequence and intercropping must be related to sustainable agriculture through soil nutrient availability. Crop residue is a good source of nutrients in many agr - ecosystems for sustainable crop production and environment (**Blanco - Canqui and Lal, 2009**). However, there was strategic food crops such as wheat (*Triticum aestivum* L.), berseem (*Trifolium alexandrinum* L.) as a forage crop and faba bean (*Vicia faba*) during the winter season. Thus, it is important to address our efforts to this fundamental issue by increasing crop productivity per unit area in the summer season with the proper choice of preceded winter field crop. Therefore, the main objective of the present research was to decrease N inputs of maize crop by intercropping cowpea with maize and increase farmers' benefit.

MATERIAL AND METHODS

A research was carried out at Mallawi Agricultural Experiments and Research Station, El-Minia governorate (31°06'42" N, 30°56'45" E, 17 m a. s. l.), Egypt, during 2013/2014 and 2014/2015 seasons. Mechanical and chemical analyses of the soil (0 – 20 cm) were done by General Organization for Agricultural Equalization Fund, Agricultural Research Center, Giza, Egypt (Table 1). Methods of chemical analysis employed were as described by **Chapman and Pratt (1961)**.

Table 1. Soil nitrogen content of the experimental soil in 2014 and 2015 seasons after harvest the winter field crops and before growing maize and cowpea.

The preceded crop	Growing season					
	2014			2015		
	N (ppm)	P (ppm)	K (ppm)	N (ppm)	P (ppm)	K (ppm)
Berseem	42.00	34.00	222.00	48.00	30.00	237.00
Faba bean	32.00	23.00	197.00	36.00	18.00	210.00
Wheat	12.00	10.00	158.00	15.00	11.50	172.00

This experiment included eighteen treatments which were the combinations of three preceded winter field crops (berseem cv. Giza 6, faba bean cv. Misr 1 and wheat cv. Giza 168) , three mineral N fertilizer rates of maize (285.6 kg N/ha, 249.9 kg N/ha and 214.2 kg N/ha were expressed as 100.0, 87.5 and 75.0% of the recommended mineral N fertilizer rate of maize) and two cropping systems (intercropping cowpea with maize and sole culture of maize) in addition to sole culture of cowpea. Varieties of maize and cowpea were T.W.C.310 and Karim 1, respectively, were used.

In the two growing seasons, berseem, faba bean and cowpea seeds were inoculated by *Rhizobium trifolii*, *Rhizobium leguminosarum* and the specific *Rhizobium* strain, respectively, before seeding it and gum Arabic was used as a sticking agent. In the two winter seasons, wheat grains and berseem seeds were drilled at the rate of 166.6 and 59.5 kg per ha, respectively. Faba bean seeds were grown in both sides of the ridge and were distributed to two plants/hill spaced at 20 cm. In the two summer seasons, maize was sown in one side of ridge (70 cm width) with growing one plant/hill spaced at 30 cm under intercropping and sole cultures, meanwhile, cowpea seeds were drilled in the other side of maize ridge under intercropping culture and in both sides of the ridge under sole culture with growing two plants/hill spaced at 20 cm. In other words, the planting densities of intercropped maize with cowpea were equal to 100 and 50% of sole maize and cowpea plant densities, respectively. Sole crops were used to estimate the competitive relationships. All the tested crops were grown in accordance to local agricultural practice. Water was supplied by furrow irrigation.

Calcium super phosphate (15.5%P₂O₅) at rate of 357 kg/ha and potassium sulfate (48.0%K₂O) at rate of 119 kg/ha were applied during soil preparation in the two winter seasons. The previous rates were applied during soil preparation in the two summer seasons. Mineral N fertilizer rate was applied during different growth stages of all the tested crops as follows: 35.7 kg N/ha for berseem, 35.7 kg N/ha for faba bean, 178.5 kg N/ha for wheat, 35.7 kg N/ha for cowpea. Water was supplied by furrow irrigation. Faba bean and berseem seeds were sown on 20th and 16th October in 2013 and 2014 seasons, respectively, meanwhile, wheat grains were sown on 15th and 13th November in 2013 and 2014 seasons, respectively. Cowpea seeds were sown on 20th and 17th May in 2014 and 2015 seasons, respectively, meanwhile, maize grains were sown three week later.

A split-split-plot design with three replications was used. The preceded winter field crops were randomly assigned to the main plots, cropping systems were allotted in subplots and mineral N fertilizer rates were allotted in sub subplots. The area of sub-plot was 12.6 m², it consisted of six ridges, and each ridge was 3.0 m in length and 0.7 m in width. The following traits were measured on ten guarded plants from each plot at harvest; plant height (cm), stem diameter (cm), number of ears/plant, ear length (cm), ear diameter (cm), ear weight (g) and grain yield per plant (g). Grain yield/ha (ton) was recorded on the basis of experimental plot area by harvesting all plants of each plot.

Nitrogen use efficiency (NUE)

NUE for each treatment was determined using the agronomic efficiency (AE) and partial factor productivity (PFP) indices (**Dobermann, 2007**): $AE = (Y - Y_0) / F$ and $PFP = (Y_0 / F) + AE$, where F = amount of (fertilizer) nutrient applied (kg/ha); Y = Crop yield with applied nutrients (kg/ha) and Y₀ = crop yield (kg/ha) in a control treatment with no N. A basic assumption was that N uptake is the same in fertilized and unfertilized plots. This assumption was made with a caution since soil N transformations and root development may differ between fertilized and unfertilized plots (**Weber and Day, 1996 and Brye et al., 2002**).

Competitive relationships

1. Land equivalent ratio (LER)

LER defines as the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield (**Mead and Willey, 1980**). It is calculated as follows: $LER = (Y_{ab} / Y_{aa}) + (Y_{ba} / Y_{bb})$, where Y_{aa} = Pure stand yield of crop a (maize), Y_{bb} = Pure stand yield of crop b (cowpea), Y_{ab} = Intercrop yield of crop a (maize) and Y_{ba} = Intercrop yield of crop b (cowpea).

2. Land equivalent coefficient (LEC)

LEC is a measure of interaction concerned with the strength of relationship (**Adetiloye et al., 1983**). It is calculated as follows: $LEC = L_a \times L_b$, where L_a = LER of crop a (maize) and L_b = LER of crop b (cowpea)

Monetary Advantage Index (MAI)

The price of maize and cowpea were 309.1 and 17.1 US\$ per ton (Bulletin of Statistical Cost Production and Net Return, 2013). MAI suggests that the economic assessment should be in terms of the value of land saved; this could probably be most assessed on the basis of the rentable value of this land. MAI was calculated according to the formula, suggested by **Willey (1979)**. $MAI = [Value \text{ of combined intercrops} \times (LER - 1)] / LER$

Statistical manipulation

Analysis of variance of the obtained results of each season was performed. The homogeneity test was conducted of error mean squares and accordingly, the combined analysis of the two experimental seasons was carried out. The measured variables were analyzed by ANOVA using MSTATC statistical package (**Freed, 1991**). Mean comparisons were done using least significant differences (L.S.D) method at 5 % level of probability to compare differences between the means (**Gomez and Gomez, 1984**).

RESULTS AND DISCUSSION

The preceded winter field crops

Ear length, diameter and weight, grain yields per plant and per ha were affected significantly by the preceded winter field crops in the combined data across 2013/2014 and 2014/2015 seasons, meanwhile, plant height, stem diameter, number of ears per plant and forage yield of cowpea per ha were not affected (Table 2). Ear length, diameter and weight, grain yields per plant and per ha were increased significantly by the preceded legume crop (berseem or faba bean) compared to those followed by wheat. There were no significant differences between berseem and faba bean residues on maize crop. As a result of crop sequence, grain yield per plant was increased ($P \leq 0.05$) by 18.28 and 12.40 % by the preceded berseem and faba bean crops, respectively. Also, grain yield per ha was increased by 8.97 and 7.23 % by the preceded berseem and faba bean crops, respectively. These results could be due to soil N, P and K were more available to subsequent maize plant after berseem cutting (Table 1). Consequently, there was an increase in dry matter accumulation that reflected on ear characteristics (length, diameter and weight) during maize growth and development (Table 2), especially grain yield per plant was positively and significantly correlated with ear length (**Viola et al., 2003**).

Therefore, it is recommended that cereal should be grown after legumes, which would enable using the accumulated biological N for their nutrition in more rational way (**Chalk, 1998**). These results reveal that the preceded cereal crop (wheat) decreased soil nutrient availability and increased intra-specific competition between maize plants which decreased measurements of ear characteristics (length, diameter and weight) compared with the preceded legume crops. Cobs may be considered as temporary sink and the stored photosynthates were translocated to grains during their development. Therefore, yield potential of maize plant could be affected positively or negatively by choice of the preceded winter field crop; especially grain yield per plant had positive and highly significant correlation with fresh ear weight, cob length and ear diameter (**Eleweanya et al., 2005**).

Table 2. Effect of the preceded winter field crops, cropping systems, mineral N fertilizer rates and their interactions on maize yield and its attributes, as well as, cowpea yield, combined data across 2013/2014 and 2014/2015 seasons.

Treatments		Plant height (cm)				Stem diameter (cm)				Ears/plant (no.)			
		100%	87.5%	75.0%	Mean	100%	87.5%	75.0%	Mean	100%	87.5%	75.0%	Mean
Berseem	Intercropping culture	292.37	287.71	268.58	282.88	2.26	2.12	2.01	2.13	1.07	1.04	0.99	1.03
	Sole culture	294.04	287.02	269.59	283.55	2.24	2.12	2.04	2.13	1.05	1.02	0.98	1.01
	Mean	293.20	287.36	269.08	283.21	2.25	2.12	2.02	2.13	1.06	1.03	0.98	1.02
Faba bean	Intercropping culture	285.46	281.99	264.31	277.25	2.21	2.07	2.00	2.09	1.05	1.02	0.98	1.01
	Sole culture	287.68	283.25	266.16	279.02	2.19	2.05	1.98	2.07	1.03	1.00	0.96	0.99
	Mean	286.57	282.62	265.23	278.14	2.20	2.06	1.99	2.08	1.04	1.01	0.97	1.00
Wheat	Intercropping culture	274.14	269.41	244.67	262.74	2.07	2.01	1.95	2.01	1.01	1.01	0.92	0.98
	Sole culture	275.79	271.16	245.55	264.16	2.05	1.97	1.93	1.98	1.00	0.99	0.91	0.96
	Mean	274.96	270.28	245.11	263.45	2.06	1.99	1.94	1.99	1.00	1.00	0.91	0.97
Average of cropping systems	Intercropping culture	283.99	279.70	259.18	274.29	2.18	2.06	1.98	2.07	1.04	1.02	0.96	1.00
	Sole culture	285.83	280.47	260.43	275.57	2.16	2.04	1.98	2.06	1.02	1.00	0.95	0.98
Average of mineral N fertilizers		284.91	280.08	259.80	274.93	2.17	2.05	1.98	2.06	1.03	1.01	0.95	0.99
L.S.D. 0.05 Preceded winter crops (P)					N.S.				N.S.				N.S.
L.S.D. 0.05 Cropping systems (S)					N.S.				N.S.				N.S.
L.S.D. 0.05 Mineral N fertilizer rates (N)					21.31				0.18				0.05
L.S.D. 0.05 P x S					N.S.				N.S.				N.S.
L.S.D. 0.05 P x N					23.82				0.24				0.08
L.S.D. 0.05 S x N					N.S.				N.S.				N.S.
L.S.D. 0.05 P x S x N					N.S.				N.S.				N.S.

Table 2. Continued.

Treatments		Ear length (cm)				Ear diameter (cm)				Ear weight (g)			
		100%	87.5%	75.0%	Mean	100%	87.5%	75.0%	Mean	100%	87.5%	75.0%	Mean
Berseem	Intercropping culture	21.54	21.38	20.86	21.26	5.43	5.30	4.81	5.18	222.47	209.43	186.69	206.19
	Sole culture	21.42	21.15	20.69	21.08	5.38	5.21	4.72	5.10	215.16	200.97	177.22	197.78
	Mean	21.48	21.26	20.77	21.17	5.40	5.25	4.76	5.14	218.81	205.20	181.95	201.98
Faba bean	Intercropping culture	21.49	21.30	20.78	21.19	5.40	5.20	4.73	5.11	216.14	202.38	179.86	199.46
	Sole culture	21.35	21.09	20.62	21.02	5.34	5.15	4.64	5.04	210.05	196.01	171.25	192.43
	Mean	21.42	21.19	20.70	21.10	5.37	5.17	4.68	5.07	213.09	199.19	175.55	195.94
Wheat	Intercropping culture	21.31	21.10	20.52	20.97	5.21	4.99	4.61	4.93	206.56	191.89	160.12	186.19
	Sole culture	21.22	20.97	20.41	20.86	5.13	4.90	4.49	4.84	199.12	184.73	149.45	177.76
	Mean	21.26	21.03	20.46	20.91	5.17	4.94	4.55	4.88	202.84	188.31	154.78	181.97
Average of cropping systems	Intercropping culture	21.44	21.26	20.72	21.14	5.34	5.16	4.71	5.07	215.05	201.23	175.55	197.28
	Sole culture	21.33	21.07	20.57	20.98	5.28	5.08	4.61	4.99	208.11	193.90	165.97	189.32
Average of mineral N fertilizers		21.38	21.16	20.64	21.06	5.31	5.12	4.66	5.03	211.58	197.56	170.76	193.30
L.S.D. 0.05 Preceded winter crops (P)					0.25				0.25				19.15
L.S.D. 0.05 Cropping systems (S)					0.23				0.21				15.33
L.S.D. 0.05 Mineral N fertilizer rates (N)					0.11				0.08				6.54
L.S.D. 0.05 P x S					0.26				0.27				20.93
L.S.D. 0.05 P x N					0.28				0.28				22.28
L.S.D. 0.05 S x N					0.24				0.22				17.09
L.S.D. 0.05 P x S x N					0.32				0.31				23.75

Table 2. Continued.

Treatments		Grain yield/plant (g)				Grain yield/ha (ton)				Forage yield of cowpea (ton/ha)			
		100%	87.5%	75.0%	Mean	100%	87.5%	75.0%	Mean	100%	87.5%	75.0%	Mean
Berseem	Intercropping culture	232.71	218.23	184.56	211.83	8.04	7.60	7.18	7.60	16.52	17.83	17.53	17.29
	Sole culture	223.93	210.34	174.13	202.80	7.89	7.44	7.05	7.46	35.42	35.89	35.11	35.47
	Mean	228.32	214.28	179.34	207.31	7.96	7.52	7.11	7.53	25.97	26.86	26.32	26.38
Faba bean	Intercropping culture	221.10	204.76	174.33	200.06	7.87	7.56	7.01	7.48	16.50	16.76	16.91	16.72
	Sole culture	215.12	200.71	166.05	193.96	7.73	7.41	6.90	7.34	35.61	35.12	35.08	35.27
	Mean	218.11	202.73	170.19	197.01	7.80	7.48	6.95	7.41	26.05	25.94	25.99	25.99
Wheat	Intercropping culture	204.37	187.03	145.84	179.08	7.41	6.99	6.56	6.98	15.71	16.89	16.42	16.34
	Sole culture	197.72	180.44	136.24	171.46	7.27	6.83	6.41	6.83	35.29	35.11	35.02	35.14
	Mean	201.04	183.73	141.04	175.27	7.34	6.91	6.48	6.91	25.50	26.00	25.72	25.74
Average of cropping systems	Intercropping culture	219.39	203.34	168.24	196.99	7.77	7.38	6.91	7.35	16.24	17.16	16.95	16.78
	Sole culture	212.25	197.16	158.80	189.40	7.63	7.22	6.78	7.21	35.44	35.37	35.07	35.29
Average of mineral N fertilizers		215.82	200.25	163.52	193.19	7.70	7.30	6.84	7.28	25.84	26.26	26.01	26.03
L.S.D. 0.05 Preceded winter crops (P)					28.42				0.60				N.S.
L.S.D. 0.05 Cropping systems (S)					17.07				0.42				14.79
L.S.D. 0.05 Mineral N fertilizer rates (N)					6.91				0.12				N.S.
L.S.D. 0.05 P x S					31.55				0.64				N.S.
L.S.D. 0.05 P x N					33.14				0.69				N.S.
L.S.D. 0.05 S x N					19.78				0.45				N.S.
L.S.D. 0.05 P x S x N					36.23				0.76				N.S.

So, it may be possible that there was better soil environment for the and nutrient cycling (**Arya *et al.*, 2007**) as a result of a mix of living rhizobia and dead berseem or faba bean roots near the experimental soil surface. Legumes, in contrast to cereals, have a beneficial effect on grain yield of subsequent cereal crops (**Olesen *et al.*, 2007**).

These results are in accordance with those found by **Bloem and Barnard (2001)** who found that maize yields after rotation with legumes were generally higher than the control treatments. They added that after the effect of N was accounted for via the N – corrected yield, it was evident that additional yield increases of 10% (average). Moreover, **Ali *et al.* (2015)** showed that legumes as preceding crop had increased significantly grain yield (5104 ka/ha) compared to fallow as preceding practice (3185 kg/ha). Finally, **Lamlom *et al.* (2015)** concluded that the preceded berseem crop has positive chemical and biological effects on soil fertility that improved growth and development of maize in the following season compared to those grown after wheat.

Cropping systems

Ear length, diameter and weight, grain yields per plant and per ha and forage yield of cowpea were affected significantly by cropping systems in the combined data across 2013/2014 and 2014/2015 seasons, meanwhile, plant height, stem diameter and number of ears per plant were not affected (Table 2). Ear length, diameter and weight, grain yields per plant and per ha were increased significantly by intercropping cowpea with maize in the same ridge compared to those grown under sole culture. As a result of intercropping, grain yields per plant and per ha were increased ($P \leq 0.05$) by 4.00 and 1.94%, respectively. It is known that the population of plants per square meter (density) and arrangement of individual plants within a square meter determine nutrient use and grain yield of maize (**Wade *et al.*, 1988**). Although plant density was identical between mixed pattern and sole culture, however, mixed pattern increased grain yields per plant and per ha compared to sole culture. Growing cowpea with maize in the same ridge had higher grain yield per plant and per ha than sole culture. In this concern, **Gao *et al.* (2010)** found that the grain yield of maize as an intercrop were significantly greater than those of maize as a sole crop.

These results could be attributed to maize plant benefited from biological N fixation process (BNF) by cowpea during maize growth and development. These results indicate that the fixed N of cowpea could be used by intercropped maize during growth and development of maize. There is evidence that leguminous plants can benefit the intercrop cereals in the same season through N excretion (**Eaglesham *et al.*, 1981**) and nodule decomposition (**Bonetti, 1991**). Clearly, mixed pattern played an important role to improve edaphic environmental conditions in rhizosphere of intercropped maize roots (**Wiehe and Hoflich, 1995**) which reflected positively on grain yield and its attributes (Table 2) through maximized carbon assimilation and crop productivity (**Dreccer *et al.*, 2000**) compared to sole culture.

With respect to cowpea yield, cowpea yield was decreased by 52.45% as compared to sole cowpea (Table 2). These results could be attributed to spatial arrangement of mixed pattern increased inter-specific competition between the intercrops for basic growth resources where efficiency of C_4 crops for N and water use was higher than C_3 crops (**Ghannoum *et al.*, 2011**). These results are in agreement with those obtained by **HamdAlla *et al.* (2014)** who concluded that fresh and dry forage yields of cowpea were lower in intercropping with maize than sole cowpea.

Mineral N fertilizer

Plant height, stem diameter, number of ears/plant, ear length, diameter and weight, grain yields per plant and per ha were affected significantly by mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons, meanwhile, forage yield of cowpea per ha was not affected (Table 2). It is observed that plant height and stem diameter of maize plant were increased by increasing mineral N fertilizer rate from 75.0 to 100% of the recommended mineral N fertilizer rate. Increasing mineral N fertilizer rate from 75.0 to 100% of the recommended mineral N fertilizer rate increased plant height and stem diameter by 9.66 and 9.59 %, respectively. Naturally, there was growth disadvantage of maize when maize plants received 87.5 or 75.0 % of the recommended mineral N fertilizer rate because growth resources such as water and soil N were little absorbed and converted to the lowest growth regulators and dry matter accumulation during maize growth and development stages than those received 100 % of the recommended mineral N fertilizer rate. Consequently, the increase in plant height and stem diameter might be due to the positive effect of N element on plant growth that led to progressive increase in internodes length and number during maize growth and development. It is known that plant height has been described as a measure of growth related to the efficiency in exploitation of environmental resources (**Alimohammadi *et al.*, 2011**).

Also, yield attributes of maize was increased by increasing mineral N fertilizer rate from 75.0 to 100 % of the recommended mineral N fertilizer rate. Number of ears/plant, ear length, diameter and weight, grain yields per plant and per ha was increased by 8.42, 3.58, 13.94, 23.90, 31.98 and 12.57 %, respectively, by increasing mineral N fertilizer rate from 214.2 to 285.6 kg N/ha. These results could be due to 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha) could be increased the strength of physiological source such as chlorophyll (**Wareing *et al.*, 1968**), effective age of leaves (**Nooden and Leopold, 1978**) and ear leaf N content (**El-Shamy *et al.*, 2015**) that contributed greatly in photosynthesis process during maize growth and development. These results show that the decreasing mineral N fertilizer rate from 100 to 75.0% of the recommended mineral N fertilizer rate decreased soil N availability and increased intra-specific competition between maize plants for basic growth resources especially soil N which restricted the ear characteristics (length, diameter and weight). Cobs may be considered as temporary sink and the

stored photosynthates were translocated to grains during their development. These results are in agreement with those obtained by **Bojović and Marković (2009)** who found that N content influenced from presence and ratio mineral elements in the soil and it was close link with chlorophyll content. Also, **Hokmalipour and Darbandi (2011)** revealed that chlorophyll was increased significantly by increasing N fertilizer levels.

With respect to cowpea, from self-evident there was no relationship between mineral N fertilizer rates of wheat and yield of cowpea. Similar results were obtained by **El-Shamy *et al.* (2014)** who reported that mineral N fertilizer rates of the cereal component had not any relationship with all the studied traits of the legume component under intercropping conditions.

Response of the preceded winter field crops to cropping systems

Ear length, diameter and weight, grain yields per plant and per ha were affected significantly by the preceded winter field crops x cropping systems in the combined data across 2013/2014 and 2014/2015 seasons, meanwhile, plant height, stem diameter and number of ears per plant were not affected (Table 2). It seems that there was a positive effect of the preceded berseem or faba bean crop interacted with intercropped maize and augmented ear length, diameter and weight, grain yields per plant and per ha compared to the other treatments. Accordingly, the preceded cereal crop (wheat) decreased soil nutrient availability (Table 1) and increased intra-specific competition between maize plants for above and under-ground conditions which reduced potential yield of sole maize. So, these results indicate that BNF process of cowpea (the legume component) could be integrated with the residual effect of the preceded berseem or faba bean and thereby contributed mainly to fulfill the N requirement of maize (the cereal component) by enhancing the rhizobia growth in rhizosphere of maize roots during maize growth and development. It is important to mention that the residual effect of wheat on soil nutrient availability that interacted with intercropped maize had higher ear length, diameter and weight, grain yields per plant and per ha than the interaction between the residual effect of wheat and sole maize. Naturally, the fixed N by legume can be use by intercropped cereals during their growing period and this N is an important resource for the cereals (**Shen and Chu, 2004**). These data show that each of these two factors act dependently on ear length, diameter and weight, grain yields per plant and per ha meaning that cropping systems responded differently ($P \leq 0.05$) to the preceded winter crops for ear length, diameter and weight, grain yields per plant and per ha.

Response of the preceded winter field crops to mineral N fertilizer

Plant height, stem diameter, number of ears/plant, ear length, diameter and weight, grain yields per plant and per ha were affected significantly by the preceded winter field crops x mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons (Table 2). Growing maize with the application of 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha)

had the highest of the studied traits of maize compared to the other treatments. It is expected that the residual effect of the preceded wheat crop interacted with 75.0% of the recommended mineral N fertilizer rate (214.2 kg N/ha) and resulted in a greater competition of maize plants for available soil N which restricted maize growth and development compared to the other treatments. Accordingly, the interaction between the preceded legume crop and 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha) recorded the highest values of plant height, stem diameter, number of ears/plant, ear length, diameter and weight, grain yields per plant and per ha compared to the other treatments. Certainly, N is the key element in increasing yield and mediates the utilization of potassium, phosphorus and other elements in plants (**Brady, 1984**). Also, the soil fertility status is improved by activating the soil microbial biomass (**Belay et al., 2001**). These data show that each of these two factors act dependently on ear length, diameter and weight, grain yields per plant and per ha meaning that mineral N fertilizer rates responded differently ($P \leq 0.05$) to the preceded winter crops for ear length, diameter and weight, grain yields per plant and per ha.

Response of cropping systems to mineral N fertilizer

Ear length, diameter and weight, grain yields per plant and per ha were affected significantly by cropping systems x mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons, meanwhile, plant height, stem diameter and number of ears per plant were not affected (Table 2). Obviously, the interaction between sole maize and 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha) gave the highest ear length, diameter and weight, grain yields per plant and per ha compared to the other treatments. Conversely, 75.0% of the recommended mineral N fertilizer rate of sole or intercropped maize (214.2 kg N/ha) interacted negatively with the preceded wheat crop and led to increase in inter-specific competition between sole or intercropped maize plants for basic growth resources especially soil N. Accordingly, the rate of photosynthesis which reflected on grain yield of sole or intercropped maize plant could not be maintained high during grain filling in later periods of senescence as a consequence of decrease in soil N availability compared to the other treatments. These results show that intercropping cowpea with maize interacted positively with 100 or 87.5% of the recommended mineral N fertilizer rate of maize to decrease inter-specific competition between intercropped maize plants for basic growth resources especially soil N. It is important to mention that maize plants of mixed pattern which received 87.5% of the recommended mineral N fertilizer rate (249.9 kg N/ha) had the same values of ear length, diameter and weight, grain yields per plant and per ha when received 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha). Clearly, the application of 87.5% of the recommended N rate to intercropped maize plants could be enhanced nodulation of adjacent cowpea root and promoted rhizobia growth in rhizosphere of maize root. The greater competition of maize for available soil N at high bean populations, when legumes were nearer to maize rows,

might have stimulated root nodulation of intercropped beans (**Abaidoo and Kessel, 1989**). These findings imply that there was adequate period of maize vegetative growth for inter-specific competition with cowpea on fixed N to benefit it. Maize plants of mixed pattern that received 249.9 kg N/ha could be enhanced BNF process of cowpea to fix about 12.5% of maize N requirements where nodulation and N fixation by legumes is adversely affected by higher rates of fertilizer N (**Dogra and Dudeja, 1993**). Finally, **El – Shamy *et al.* (2015)** showed that maize plant of mixed pattern that received the recommended N rate did not achieve the highest grain and total yields/ha. Adding the recommended N rate to the plant affected negatively rhizobia activity in rhizosphere of maize roots and efficiency of biological N fixation by adjacent legume plants. These data show that each of these two factors act dependently on ear length, diameter and weight, grain yields per plant and per ha meaning that mineral N fertilizer rates responded differently ($P \leq 0.05$) to cropping systems for ear length, diameter and weight, grain yields per plant and per ha.

Response of the preceded winter field crops to cropping systems and mineral N fertilizer

Ear length, diameter and weight, grain yields per plant and per ha were affected significantly by the preceded winter field crops x cropping systems x mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons, meanwhile, plant height, stem diameter and number of ears per plant and forage yield of cowpea per ha were not affected (Table 2). Intercropping cowpea with maize that received 100 or 87.5% of the recommended mineral N fertilizer rate after legume crop harvest gave the highest ear length, diameter and weight, grain yields per plant and per ha compared to the other treatments. These results could be attributed to the interaction between intercropped maize that received the medium mineral N fertilizer rate and the residual effect of the preceded berseem or faba bean crop reached the same significance level of the interaction between intercropped maize that received the highest mineral N fertilizer rate and the preceded berseem or faba bean crop. These results reveal that there was advantage of intercropping cowpea with maize that received 87.5% of the recommended mineral N fertilizer rate after berseem cutting or faba bean harvest because of nitrate could be inhibited nitrogenase activity in the legume plant nodules (**Streeter, 1988**). It is known that legumes have two sources of N nutrition – symbiotic N fixation of atmospheric molecular N in symbiosis with *Rhizobium* or *Bradyrhizobium* sp. and assimilation of soil N (mainly in the form of nitrates), using the enzyme nitrate reductase (**Arrese-Igor *et al.*, 1990**). Thus, the bacteria that actually fixed the N become lazy and N fixing declines (**Braunwart *et al.*, 2001**). Accordingly, the efficiency of BNF process was not enhanced by the integration between the preceded legume (berseem or faba bean) crop and the recommended mineral N fertilizer dose. These data show that there was effect ($P \leq 0.05$) of the preceded winter field crops x cropping systems x mineral N fertilizer rates on ear length, diameter and weight, grain yields per plant and per ha.

Nitrogen use efficiency (NUE)

The preceded winter field crops

Partial factor productivity (NUE–PFP) expressed as crop yield per unit of N applied (Roberts, 2008) are indicative of the degree of economic and environmental efficiency in use of nutrient inputs. In this study, NUE ranges from 101.81 to 212.88 kg grain yield per kg nutrient applied (Figure 1). NUE values of 40–80 kg/kg are usual with values > 60 kg/kg for NUE being common in well–managed systems or at low levels of N use, or at low soil N supply (Doberman, 2007). The preceded berseem crop had the highest ($P \leq 0.05$) NUE compared to that of the other preceded crops (Figure 1). These results could be due to the increase in soil N content after berseem cutting (Table 1) which increased absorption N uptake from soil by maize roots. Consequently, this status led to more assimilation into amino acids that serve as N carriers throughout the plant and N transport from source to sink tissues throughout plant development, especially during the grain filling period (Table 2).

Cropping systems

NUE was affected significantly by cropping systems in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). Growing cowpea in the other side of maize ridge increased NUE by 2.06% compared with that of sole maize. These results could be due to maize plant benefited from BNF process of cowpea that reflected positively on grain yield per plant (Table 2). Similar results were obtained by Gao *et al.* (2010) who showed that N uptake of maize as an intercrop was significantly greater than those of maize as a sole crop. Also, El-Shamy *et al.* (2015) showed that legume crop improved N use efficiency (NUE) for maize plant of mixed pattern. Finally, Zhang *et al.* (2015) indicated that intercropping systems reduced use of N fertilizer per unit land area and increased relative biomass of intercropped maize, due to promoted photosynthetic efficiency of border rows and N utilization during symbiotic period.

Mineral N fertilizer

NUE was affected significantly by mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). Maize plants with the application of 87.5% of the recommended mineral N fertilizer rate increased ($P \leq 0.05$) NUE by 89.70 % compared to that of maize plants with the application of 100% of the recommended mineral N fertilizer rate.

These results reveal that NUE was influenced by available soil N in the experimental soil and it was close link with mineral N fertilizer. It is observed that NUE values emerging from this study apply to low levels of N use, or at low soil N supply and contributed positively in increase of photosynthesis process efficiency and consequently grain yield/plant (Table 2).

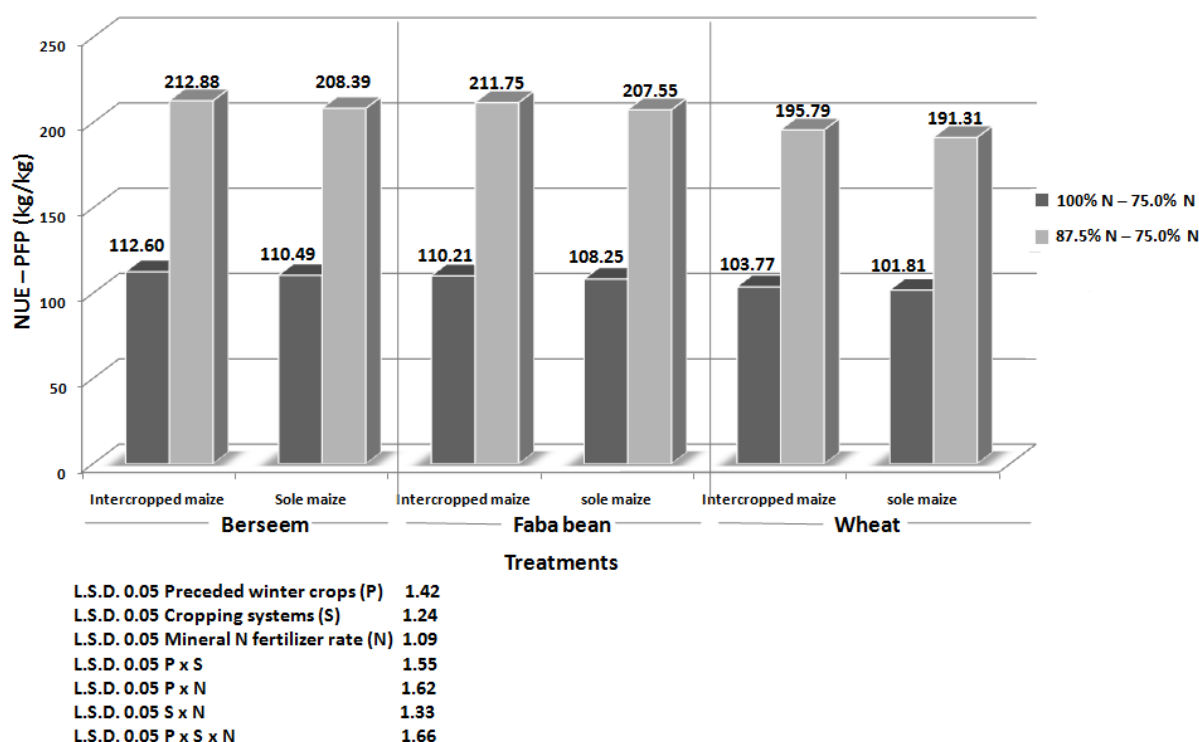


Figure 1. NUE as affected by the preceded winter field crops, cropping systems, mineral N fertilizer rates and their interactions, combined data across 2013/2014 and 2014/2015 seasons.

Similar results were obtained by **El-Shamy *et al.* (2015)** who found that adding 83.33% of the recommended mineral N fertilizer rate N to the plant increased ($P \leq 0.05$) NUE by 97.74 percent compared to those that received 100% of the recommended mineral N fertilizer rate.

Response of the preceded winter field crops and cropping systems

NUE was affected significantly by the preceded winter field crops in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). NUE of intercropped maize was increased after berseem cutting, meanwhile growing maize alone after wheat harvest had the lowest NUE compared to the other treatments. These results could be due to the preceded cereal crop (wheat) decreased soil nutrient availability (Table 1) which increased intra-specific competition between maize plants for above and under-ground conditions and reduced potential yield of sole maize. So, these results indicate that BNF process of cowpea (the legume component) could be integrated with the residual effect of the preceded berseem and thereby contributed mainly to fulfill the N requirement of maize (the cereal component) by enhancing the rhizobia growth in rhizosphere of maize roots during maize growth and development.

Response of the preceded winter field crops to mineral N fertilizer

NUE was affected significantly by the preceded winter field crops x mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). Growing maize with the application of 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha) after berseem

cutting had the highest NUE, meanwhile, maize plants that received 75% of the recommended mineral N fertilizer rate after wheat harvest had the lowest NUE compared to the other treatments. It is expected that the preceded wheat crop interacted with 75.0% of the recommended mineral N fertilizer rate (214.2 kg N/ha) and resulted in a greater competition between maize plants for available soil N which affected negatively N uptake of maize plant. These data show that each of these two factors act dependently on NUE meaning that mineral N fertilizer rates responded differently ($P \leq 0.05$) to the preceded winter crops for NUE.

Response of cropping systems to mineral N fertilizer

NUE was affected significantly by cropping systems x mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). Intercropping cowpea with maize plants with the application of 87.5% of the recommended mineral N fertilizer rate had the highest NUE compared to the other treatments. These data may be due to adding 87.5 % of the recommended mineral N fertilizer rate promoted rhizobia growth in rhizosphere of intercropped maize roots which reflected positively on N uptake and IAA content in tissues of maize plant which contributed strongly with in enhancing efficiency of photosynthesis process and the grain yield/plant compared to the other treatments. Intercropping cowpea with maize that received 100% of the recommended mineral N fertilizer rate could be affected negatively rhizobia activity in rhizosphere of intercropped cowpea roots which reflected negatively on NUE of intercropped maize plant. These results are in parallel with those obtained by **El-Shamy *et al.* (2015)** who found that adding 83.33% of the recommended N rate to maize plants promoted rhizobia growth in rhizosphere of maize roots and increased N uptake and IAA content in tissues of the plant which increased NUE of intercropped maize compared to those received the full mineral N fertilizer rate.

Response of the preceded winter field crops to cropping systems and mineral N fertilizer

NUE was affected significantly by the preceded winter field crops x cropping systems x mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). Intercropping cowpea with maize that received 87.5% of the recommended mineral N fertilizer rate after berseem cutting had the highest NUE, meanwhile, sole maize that received 75.0% of the recommended mineral N fertilizer rate had the lowest NUE compared to the other treatments. These results reveal that there was advantage of intercropping cowpea with maize that received 87.5% of the recommended mineral N fertilize rate after berseem cutting could be increased efficiency of BNF process of cowpea that reflected positively on NUE of intercropped maize plant. Intercropping cowpea with maize that relieved 100% of the recommended mineral N fertilizer rate after berseem cutting did not achieve the highest NUE because of nitrate could be inhibited nitrogenase activity in the legume plant nodules (**Streeter, 1988**). It is known that legumes have two sources of N nutrition – symbiotic N fixation of atmospheric molecular N in symbiosis with

Rhizobium or *Bradyrhizobium* sp. and assimilation of soil N (mainly in the form of nitrates), using the enzyme nitrate reductase (Arrese-Igor *et al.*, 1990). Thus, the bacteria that actually fixed the N become lazy and N fixing declines (Braunwart *et al.*, 2001). Accordingly, the efficiency of BNF process of cowpea was affected negatively by increasing soil N availability after berseem cutting (Table 1) which decreased UNE of intercropped maize that received 100% of the recommended mineral N fertilizer rate. These data show that there was effect ($P \leq 0.05$) of the preceded winter field crops x cropping systems x mineral N fertilizer rates on NUE.

Competitive relationships

Land equivalent ratio (LER)

The values of LER were estimated by using data of recommended sole cultures of both crops. Intercropping cowpea with maize increased LER as compared to sole cultures of both crops in the combined data across 2013/2014 and 2014/2015 seasons (Figure 2). It was ranged from 1.37 (by intercropping cowpea with maize that received 75.0% of the recommended mineral N fertilizer rate after wheat harvest) to 1.50 (by intercropping cowpea with maize that received 100% of the recommended mineral N fertilizer rate after faba bean harvest). The results showed that maize was superior in the intercrop system where the relative yield was increased of sole culture, meanwhile, cowpea was inferior companion crop where the relative yield was decreased of sole culture in the combined analysis.

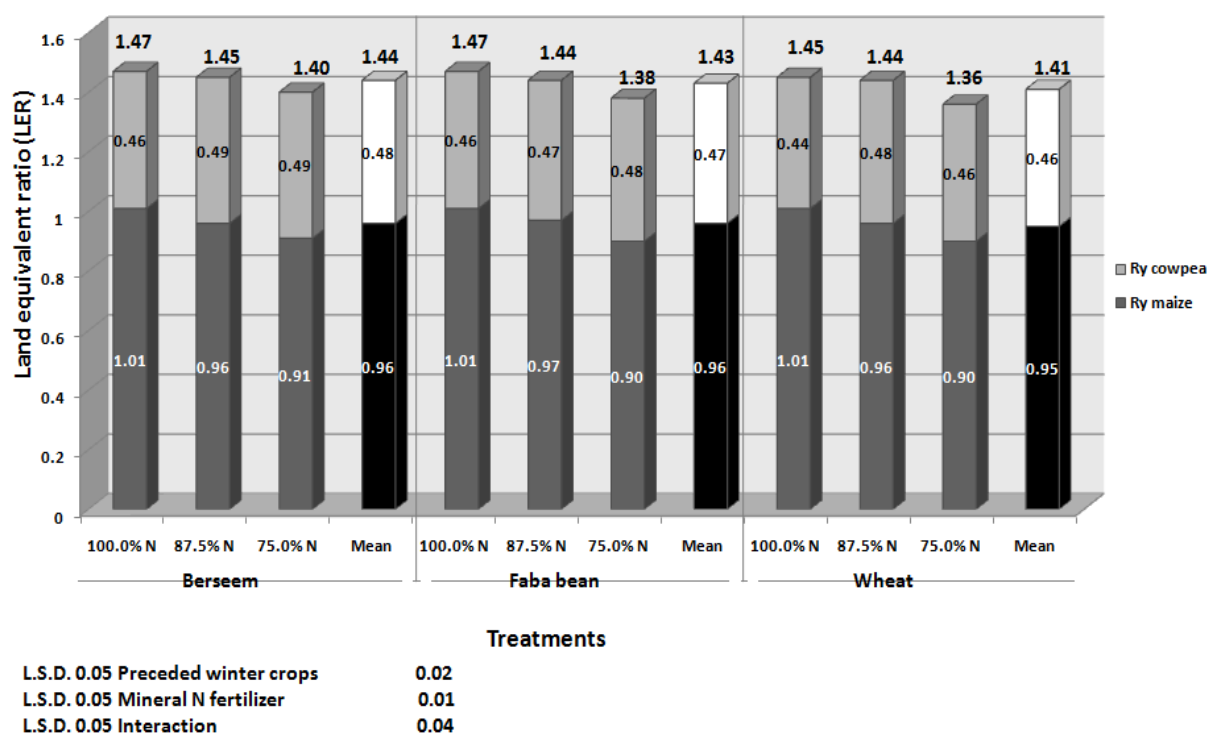


Figure 2. LER as affected by the preceded winter field crops, cropping systems, mineral N fertilizer rates and their interactions, combined data across 2013/2014 and 2014/2015 seasons.

LER was affected significantly by the preceded winter field crops in the combined data across 2013/2014 and 2014/2015 seasons (Figure 1). The advantage of the highest LER by intercropping cowpea with maize after harvest legume crop (berseem or faba bean) over the others could be due to residual effect of legume crop increased soil nutrient availability (Table 1) for intercropping cowpea (50 % of sole cowpea plant density) with maize (100% of sole maize plant density) which reflected positively on relative yields of both crops. These results are in accordance with those obtained by **HamdAlla *et al.* (2014)** who concluded that the actual productivity was higher than expected productivity.

LER was affected significantly by mineral N fertilizer in the combined data across 2011 and 2012 seasons. These results show that the decreasing mineral N fertilizer rate from 100 to 75.0% of the recommended mineral N fertilizer rate decreased soil N availability and increased intra-specific competition between maize plants for basic growth resources especially soil N.

LER was affected significantly by the interaction between the preceded winter field crops and mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons. These results may be due to the interaction between the preceded legume crop and 100% of the recommended mineral N fertilizer rate (285.6 kg N/ha) increased N content in tissues of maize plants especially N is the key element in increasing yield and mediates the utilization of potassium, phosphorus and other elements (**Brady, 1984**).

2. Land equivalent coefficient (LEC)

LEC was a measure of interaction concerned with the strength of relationship. LEC is used for a two- crop mixture the minimum expected productivity coefficient (PC) is 25 percent, that is, a yield advantage was obtained if LEC value was exceeded 0.25. LEC was affected significantly by the preceded winter field crops in the combined data across 2013/2014 and 2014/2015 seasons (Figure 3). The disadvantage of the lowest LER by intercropping cowpea with maize after harvest wheat over the others could be due to the preceded wheat crop decreased soil nutrient availability (Table 1) for intercropping cowpea with maize which reflected negatively on relative yields of both crops.

LEC was affected significantly by mineral N fertilizer in the combined data across 2011 and 2012 seasons (Figure 3). These results show that the decreasing mineral N fertilizer rate from 100 to 75% of the recommended mineral N fertilizer rate decreased soil N availability and increased intra-specific competition between maize plants for basic growth resources especially soil N.

LEC was affected significantly by the interaction between the preceded winter field crops and mineral N fertilizer in the combined data across 2013/2014 and 2014/2015 seasons (Figure 3).

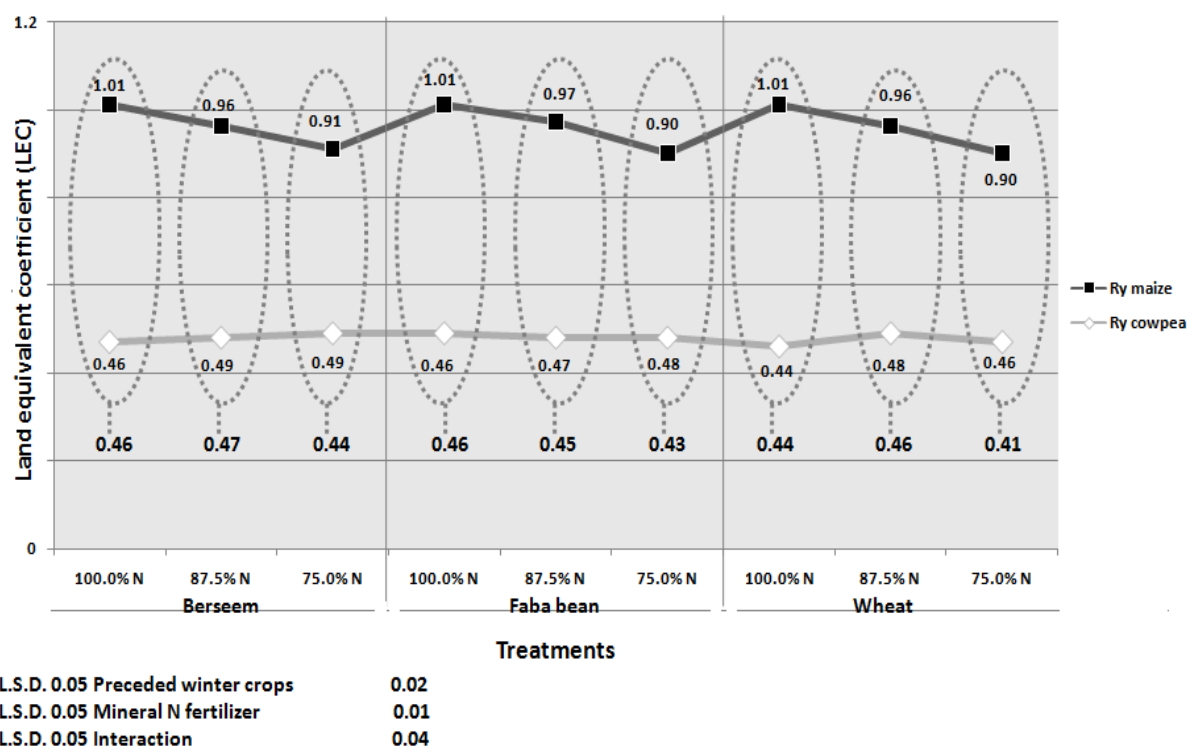


Figure 3. LEC as affected by the preceded winter field crops, cropping systems, mineral N fertilizer rates and their interactions, combined data across 2013/2014 and 2014/2015 seasons.

These results may be due to the interaction between the preceded wheat crop and 75.0% of the recommended mineral N fertilizer rate decreased N content in tissues of maize plants especially N is the key element in increasing yield and mediates the utilization of potassium, phosphorus and other elements (Brady, 1984).

Intercropping Economic Advantage

The economic performance of the intercropping was evaluated to determine if maize and cowpea combined yields are high enough for the farmers to adopt this system. The averages of monetary advantage index (MAI) values of intercropping cowpea with maize that received 100 or 87.5% of the recommended mineral N fertilizer rate after berseem cutting were higher than the other treatments (Figure 4). Differences between the highest and the lowest values were 274 US\$ in the combined data across 2013/2014 and 2014/2015 seasons. On the other hand, there were gradual and consistent decreases in MAI values with decreasing mineral N fertilizer rate from 100 to 75.0% of the recommended mineral N fertilizer rate of intercropped maize with cowpea. Intercropping cowpea with maize that received 87.5% of the recommended mineral N fertilizer rate after berseem cutting resulted in high MAI and could be recommended. These results are in parallel with those observed by Hamdalla *et al.* (2014) who concluded that values of MAI were 2097.28, 2607.95 and 2360.80 in both seasons and the combined analyses.

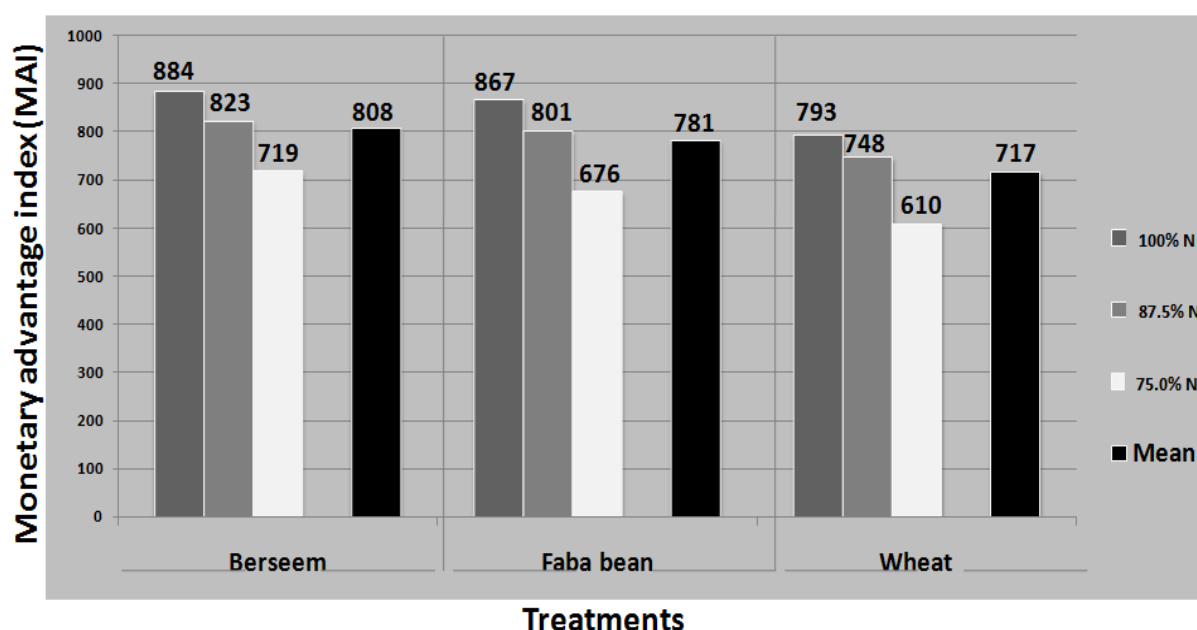


Figure 4. MAI as affected by the preceded winter field crops, cropping systems, mineral N fertilizer rates and their interactions, combined data across 2013/2014 and 2014/2015 seasons.

CONCLUSION

It could be concluded that intercropping cowpea with maize that received 87.5% of the recommended mineral N fertilizer after berseem cutting compensated 12.5% of maize N requirements under Egyptian conditions.

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