

Effects of Crop Rotation and N-P Fertilizer Rate on Grain Yield and Related Characteristics of Maize and Soil Fertility at Bako, Western Oromia, Ethiopia

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Abstracts: A trial was conducted to determine the effects of crop rotation with N-P rates on grain yield of maize and soil fertility in Bako over a period of five years. The experiment was laid out in a randomized complete block design in factorial arrangement with rotation crops (Niger seed, haricot bean and tef) as main factor and two levels of NP fertilizers (half recommended (55/23 kg N-P₂O₅ ha⁻¹ and recommended (110/46 kg N-P₂O₅ ha⁻¹) rate as sub factor and continuous maize with three replications. Higher mean grain yield of maize was recorded from maize following rotation crops with recommended rate of fertilizer compared to continuous maize. Maize following rotation crops gave mean grain yield advantage of 640 to 830 and 1921 to 1968 kg ha⁻¹ compared to continuous maize at half and full recommended N-P fertilizer rate. Maize following Niger seed produced mean grain yield advantage of 971 and 1527 kg ha⁻¹ compared to haricot bean and tef. Primary nutrient (N, P and K) composition of the tissue and grain of maize were significantly higher with maize following rotation crop compared to continuous maize, indicating the enhancement of the nutrient use efficiency of maize following rotation crops. Crop rotation with fertilizer amendment improved the pH of the soil. Crop rotation and N-P amendment enabled maize yields and soil fertility to be maintained at a higher level. Multiple advantages accrue from the use of crop rotation. Higher grain yield and high net return of maize were realized following Niger seed, haricot bean and tef compared to continuous maize. Maize following Niger seed followed by haricot bean with the recommended rate of fertilizer is a better management option for sustainable maize production in Western Oromia.

Keywords: Crop Rotation; Niger Seed; N-P Rate

1. Introduction

Soil degradation is occurring at an alarming rate and threatens soil productivity and maize production in Western Oromiya due to continuous cropping over the last three decades. Conventional agriculture (continuous cropping with inputs) has certain limitations in terms of maintaining long-term soil fertility (Charpentier *et al.*, 1999). Longer cultivation has further depleted the soil organic-matter content and fertility (Wu *et al.*, 2003). Crop rotation is the most among factors significantly increasing soil organic matters (Campbell *et al.*, 1996). Legume-cereal and Oilseed- cereal sequence is the predominant cropping pattern practice by smallholder farmers in western Ethiopia (Asfaw *et al.*, 1997). Crop rotation is necessary and the desirable management option to restore, maintain, enhance soil fertility, and maximize yield. Appropriate cropping sequence with continuous use of chemical fertilizers can increase the yield of annual crops in Alfisols (Heno and Bannante, 1999), which may be true for maize at Bako. Singh *et al.* (1987) reported that maize-wheat cropping systems with chemical fertilizers increased the grain yield of maize by 202 % and of wheat by 176 % compared to non-fertilized controls. The highest maize yield of 4550 kg/ha was obtained from the annual crop rotation of berseem (*Trifolium alexandrinum*) - maize followed by grain legume-maize sequence (3810 to 3870 kg/ha) (Ramteke *et al.*, 1986). Rotations with legumes built up the N status of the soil. According to Zentner *et al.* (2001) N-requirement of wheat in continuous wheat or wheat-lentil rotation varied from 5 to 60 kg ha⁻¹. The available soil N was increased by about 32 and 40 kg/ha following chickpea and lentil compared

to the preceding wheat (Patwary *et al.*, 1989). Alvey *et al.* (2001), in their work, suggested that a wide spread use of cereal/legume rotations has been proposed as a means of sustainability to meet increasing food demands. Nugusse (1995) found that Haricot bean is the best precursor crop for maize at Awassa and Nazareth. Rao and Mathuva (2000) found that maize following annual legumes were 32 - 49 % more profitable than continuous maize. However, Tadesse and Tolessa (1998) reported that Niger seed is the best precursor crop for maize with a yield advantage of 50 % compared to sole cropping followed by haricot bean. Including oilseed crops in rotation with wheat may also increase soil productivity because of their deep root system to scavenge nutrients from lower root depths. It also produces root channels which may facilitate root development in subsequent cereal crop (Angus *et al.*, 1991).

Maintenance of the soil fertility at the economic optimum level with appropriate crop rotation and affordable fertilizer rate is essential for sustainable maize production in the region. Identification of suitable crop rotation with optimum fertilizer was more reliable and generally maximized maize grain yield. Therefore, the objective of this study was to determine the appropriate crop rotation with optimum N-P rate for maize production.

2. Materials and Methods

A Crop rotation experiment was conducted during the 1999 to 2003 cropping seasons at Bako Agricultural Research Center (BARC), situated in Western Oromia, Ethiopia. The center is located in East Wollega Zone of the Oromia National Regional State. Geographically, it is

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located between 9°6'N latitude and 37°09'E longitude. It has an aerial coverage of about 38 square kilometres; with a mean altitude of 1650 meters above sea level. The long-term (1961 - 2003) mean annual rainfall at BARC is 1239 mm with unimodal distribution. It has a warm humid climate with mean minimum, mean maximum and average air temperatures of 13.2, 28 and 21°C, respectively (NMSA, 2003). Sixty percent of the soil (1400 ha) at Bako Research Center, is reddish brown in colour, clay and loam in texture (Wakene, 2001).

Agro-ecologically, BARC is classified as tepid to cool sub humid mid highlands and is a mixed farming zone, encompassed by Gibe River and with abundant natural vegetation, and grasslands. The major annual and perennial crops of the area include maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Monch), teff (*Eragrostis tef* (Zucc.) Trotter), noug (*Guizotia abyssinica*), hot pepper (*Capsicum frutescens* L.), haricot bean (*Phaseolus vulgaris* L.), sweet potato (*Ipomoea batatas* Lam.), mango (*Mangifera indica* L.), banana (*Musa* spp), and sugar cane (*Saccharum officinarum* L.) in order of importance (Asfaw *et al.*, 1997). During the 1999 cropping season, the trial area was sown to maize with recommended fertilizer (110/46 kg N/P₂O₅ ha⁻¹) in order to make the field uniform. First, in the 2000 cropping season, rotation crops sown were local Niger seed (*Guizotia abyssinica*) and teff (*Eragrostis Tef* (Zucc.) Trotter), and Roba-1 of haricot bean (*Phaseolus vulgaris* L.) varieties as well as continuous maize. During the 2001 cropping season, maize hybrid (BH-660) was sown with two levels of fertilizers, half recommended (55/23 kg N-P₂O₅ ha⁻¹ and recommended (110/46 kg N-P₂O₅ ha⁻¹) rate for the area.

In addition, during the 2002 cropping season, rotation crops (Niger seed, haricot bean and teff) and continuous maize were sown. During the 2003 cropping season, again maize hybrid (BH-660) was sown with two levels of fertilizers, half recommended (55/23 kg N-P₂O₅ ha⁻¹ and recommended (110/46 kg N-P₂O₅ ha⁻¹) rate for the area. The rotation system was one phase rotation cycle. The main factors were teff (*Eragrostis Tef* (Zucc.) Trotter), Niger seed (*Guizotia abyssinica*), and Haricot bean (*Phaseolus vulgaris* L.) and control maize (*Zea mays* L.) with recommended fertilizer rate. The seed rates used were 25 kg ha⁻¹ for teff, 8 kg ha⁻¹ for Niger seed and 75 kg ha⁻¹ for Haricot bean.

The experiment was laid out in a randomized complete block design in factorial arrangement with rotation crops as main factor and N-P rate as sub-factors. The total gross plot size was 5.1 x 4.5 m with 3 x 5.1m net plots. The spacing was 75 x 30 cm. The seed rate used for maize was 25 kg ha⁻¹. Sowing dates followed recommended date of planting ranged May 1 - 30. Full dose of phosphorus (as DAP) was applied once at planting, while nitrogen (as Urea) was applied in split doses, half at planting and the remaining half applied 30 to 40 days after planting. The maize grain yield was adjusted at 12.5 % moisture level and given in kg ha⁻¹. The data were analysed using MSTAT-C statistical packages (Freed *et al.*, 1989).

The soil sample was collected at the depth 0 - 20 cm with augur three times, first before application of the

treatment (1999), second after harvesting of the rotational crops in 2000 and when the field was ready for maize planting; third after harvesting of the main crop maize in 2003. Determination of soil particle size distribution was carried out using the hydrometer method (Dewis and Freitas, 1984). Soil pH was measured using digital pH meter in 1:2.5 soil to solution ratio with H₂O. Exchangeable basis were extracted with 1.0 Molar ammonium acetate at pH 7. Ca and Mg in the extract were measured by atomic absorption spectrophotometer while Na and K were determined using flame photometry (Van Reeuwijk, 1992). Cation exchange capacity of the soil was determined following the modified Kjeldahl procedure (Chapman, 1965) and reported as CEC of the soil. Percent base saturation was calculated from the sum of exchangeable basis as a percent of the CEC of the soil. Exchangeable acidity was determined by extracting the soil samples with M KCL solution and titrating with sodium hydroxide as described by McLean (1965). Organic carbon was determined following wet digestion methods as described by Walkley and Black (1934) whereas kjeldahl procedure was used for the determination of total N as described by Jackson (1958). The available P was measured by Olsen method as described by Olsen *et al.* (1954) and Bray II method (Bray and Kurtz, 1945). The electrical conductivity was estimated from saturated extracts of soil samples.

Plant tissues (leaves, stalk and grain) in 2001 and (leaves and stalk) in 2002 were collected during harvesting of maize crop. The plant tissue collected was analyzed in National Soil Research Center laboratory using standard procedures for different selected nutrient compositions.

For partial budget and marginal rate of return analysis, maize grain yield was valued at an average open market price of EB 265 per 100 kg for the last 10 years and maize seed price was EB 500 per 100 kg. Labour cost for field operation was EB 7 per man-day. The yield was adjusted down by 10% to reflect actual production conditions (CIMMYT, 1988). The cost of fertilizers (Urea and DAP) amounted to EB 606 and 857 per 100 kg at the current market price.

3. Result and Discussion

3.1. Cropping Season

The results of maize grain yield in 1999 and continuous maize and rotational crops in 2000 and 2002 cropping season are shown in (Table 1). The grain yields of different crops indicated the variation of yield across cropping seasons. Combined yields across years averaged 5615 kg ha⁻¹, but 6641 and 4579 kg ha⁻¹ in 2001 and 2003 cropping seasons (Table 3). Mean plant height over years averaged 267 cm, but 290 and 244 cm in 2001 and 2003 cropping seasons (Table 3). Higher mean plant height and grain yield were found in 2001 cropping season. This might be due to the prevailing environmental conditions (sunshine, rainfall and temperature) during the growing seasons (Table 3). Year significantly ($p < 0.05$) affected mean plant height and grain yield of maize but non-significantly affected 1000 seed weight (Table 2 and 3). This might be due to the variation in climatic factors

during the growing period of maize. Year by cropping rotation interaction significantly ($p < 0.05$) affected plant height and grain yield of maize indicating that the performance of rotational crops affects their residual effects and their contribution to soil fertility and grain yield of maize. Thus, cropping sequence consideration during crop rotation plays a significant role in the enhancement of soil fertility and grain yield of maize. In

2001 cropping season, higher mean plant height and grain yield of maize was recorded following haricot bean compared to Niger seed and tef. However, higher 1000 seed weight of maize was recorded following Niger seed and tef crops, respectively. Higher mean plant height, 1000 seed weight and grain yield maize were recorded following Niger seed compared to haricot bean and tef in 2003 and combined over years (Table 4).

Table 1. Mean grain yield of maize in 1999 and rotational crops (2000 and 2002) and continuous maize from 2000 to 2002.

Maize (kg ha ⁻¹)		Yield (kg ha ⁻¹)		
1999	Rotation crops	2000	2001	2002
4870	Niger seed	742		734
4708	Niger seed	749		664
6070	Haricot bean	1436		1810
5738	Haricot bean	1422		1897
4697	Tef	356		396
4515	Tef	392		464
5567	Continuous maize	8270	5544	2957

3.2. Plant Height

Crop rotation significantly ($p < 0.05$) affected mean plant height in 2003 and combined over years but had a non-significant ($p > 0.05$) effect in 2001 (Table 2 and 3). Mean plant height in 2003 and combined over years were significantly ($p < 0.05$) affected by N/P fertilizer rate (Tables 2 and 3). Plant height significantly increased with the rate of fertilizers. Recommended N-P rate gave higher plant height compared to half recommended in 2001, 2003 and combined over years (Table 3). The interactions of crop rotation and N-P fertilizer rate non-significantly ($p > 0.05$) affected mean plant height of maize (Table 2 and 3). Higher mean plant height of maize was observed from all three cropping sequences with recommended fertilizer compared to with half recommended (Table 3). This justifies the assertion that cropping sequence by itself does not boost the performance of maize without appropriate fertilizer rate.

3.3. Thousand Seed Weight

Cropping sequence and N-P rates non-significantly ($p > 0.05$) affected thousand seed weight (Table 2 and 3). The interactions of cropping sequence and N-P fertilizer rate non-significantly affected mean 1000 seed weight of maize (Table 2 and 3). Higher mean thousand seed weight of maize was recorded following cropping sequence with recommended fertilizer compared to half recommended (Table 3).

3.4. Grain Yield

Cropping sequence significantly ($p < 0.05$) affected mean grain yield in 2003 and combined over years but had a non-significant effect in 2001 (Table 2 and 3). This revealed that cropping sequence had a significant effect on grain yield increment of maize. Maize following Niger seed produced 971 and 1255 kg ha⁻¹ higher combined grain yield advantage compared to following haricot bean and tef (Table 4). Mean grain yield was significantly ($p < 0.05$) affected by N-P fertilizer rate (Table 2, 3 and 4).

Grain yield significantly increased with the rate of fertilizers. Mean grain yield increased by 1281, 1138 and 1209 kg ha⁻¹ respectively as the rate of N-P increased from half recommended to recommended rate in 2001, 2003 and combined over years (Table 4). This justifies the claim that crop rotation with recommended dose of N-P fertilizers significantly increased grain yield of maize. Similarly, Shepherd and Sylvester-Bradley (1996) reported that the performance of succeeding crop was apparent when high, super-optimal fertilizer levels had been applied to preceding crops. Crop rotation by N-P fertilizer rate interaction non-significantly affected mean grain yield of maize (Table 2 and 3).

Maize following haricot bean produced higher mean grain yield at half recommended and recommended fertilizer compared to following Niger seed and tef in 2001 cropping season (Table 4). This might be due to the free nitrogen fixed by legumes in the soil which ameliorates the nitrogen status of the soil compared to oil crops and cereals. Conversely, maize following Niger seed in 2003 cropping season and combined over years gave a higher mean grain yield with half recommended fertilizer and recommended fertilizer compared to following haricot bean and tef (Table 3 and 4).

All crop rotations produced greater yield advantage of maize compared to continuous maize with recommended and half recommended fertilizer rates. At half the recommended fertilizer rate mean grain yield advantages of 640, 830 and 735 kg ha⁻¹ were obtained following rotation crops compared to continuous maize in 2001, 2003 and combined across years (Table 3 and 4). However, at recommended fertilizer rate, maize following rotation crops gave mean grain yield advantage of 1921, 1968 and 1944 kg ha⁻¹ compared to continuous maize in 2001 and 2003 cropping season and combined over years (Table 3 and 4). In the same way, Higgs *et al.* (1990) reported 10 to 17 % greater yield for corn grown in rotation with other crops compared to continuous cropping. A Similar result was reported by Halvorson *et*

al. (2000); and Soper and Grenier (1987). Crop rotations with recommended fertilizer application produced better grain yield of maize. Similarly, Habtamu *et al.* (1996) found that crop rotation is more productive if it is supplemented with fertilizer application. The sustainable production of maize is possible by integrating crop rotation with recommended fertilizer levels. Sayre (1999) suggest that sustainable crop production practices involve the use of break crops and optimum fertilizer application which minimize nutrient losses. This could be due to the improvement in soil fertility status with different crops compared to continuous maize. The result agrees with (Reddy *et al.*, 1994); and (Riedell *et al.*, 1998). The higher yield of maize in crop rotation is due to the change in spatial and temporal difference of crops with time dimensions. In addition, variation in root structure and depth is one of the other benefits of crop rotation for change in soil fertility and can influence yield of crops by altering the physical and morphological properties of the soil. Higher mean grain yield increases of maize were achieved following Niger seed compared to haricot bean and tef with recommended and half recommended fertilizer rate. For sustainable production of maize, the

use of different crop rotations with recommended and half recommended fertilizer rates are better than continuous planting of maize.

3.5. Soil Chemical and Physical Properties

The soil pH in H₂O ranged from 5.0 to 5.5 and 3.7 to 4.9 in KCl in 2000 (Table 5). According to FAO, 1990 and Landon, 1991 such soils are acidic to strongly acidic. The soil pH in H₂O ranged from 5.9 to 6.1 in 2003 (Table 6), indicating change in soil reaction from strongly acidic to moderately acidic. Crop rotation and N-P amendment significantly increased pH of the soil. Total N ranged from 0.13 to 0.17 % in 2000 (Table 5) and 0.15 to 0.18 % in 2003 (Table 6), which is categorized as low range according to FAO (1990). Soil from haricot bean field gave higher total N than from Niger seed and Tef crop fields (Table 5 and 6). This might be attributed to the nitrogen fixing nature of haricot bean. Similarly, Kumar *et al.* (1983); and Holford and Crocker (1997) reported legumes in crop rotation improve soil fertility, particularly soil N content.

Table 2. Mean square for plant height, 1000 seed weight and grain yield of maize for each year and across two years at Bako.

Source of variation	DF	Mean square								
		Plant height (cm)			1000 seed weight (g)			Grain yield (kg ha ⁻¹)		
		2001	2003	combined	2001	2003	combined	2001	2003	combined
Year	1			18815**			355			37266465**
Rotation crops (A)	2	2510	620.20**	1380**	1231	5317	3753	2030640	9293369**	5199292**
N-P fertilizer rate (B)	1	1300	4050**	4970**	20.06	5760	2550	7385041**	5828836**	13167898**
A x B	2	1524	1.167	799	184	2061	988	396311	80474	309123
Year x A	2			1749			2795			6124717**
Year x B	1			380			3230			45979
Year x A x B	2			727			1257			167662
Error	10 (20)	620.7	100.533	360.628	864.19	3108.6	1986	898233	148720	523476
CV (%)		8.59	4.10	7.11	8.45	16.31	12.92	13.89	8.05	12.46

(20) Combined degree of freedom for error, ** significant at 5 % probability level

Table 3. Effects of rotation crops and N-P fertilizer rate on plant height, 1000 seed weight and grain yield of maize.

Rotation crops	N-P fertilizer rate	Plant height (cm)			1000 seed weight (g)			Grain yield (kg ha ⁻¹)		
		2001	2003	Mean	2001	2003	Mean	2001	2003	Mean
Niger seed	Half recommended	255	240	247	357	369	363	6228	5488	5858
Niger seed	Recommended	301	270	285	365	366	365	7594	6884	7239
Haricot bean	Half recommended	322	228	275	338	362	350	6484	3263	4874
Haricot bean	Recommended	305	257	281	327	334	331	8231	4333	6282
Tef	Half recommended	267	220	243	346	347	347	5839	3909	4874
Tef	Recommended	290	250	270	355	271	313	6569	4858	5713
Continuous	Recommended	322	251	273	327	374	350	5544	3390	4467
Mean		295	245	268	345	346	346	6641	4589	5615
LSD (5%)	Rotation crops	Ns	12.90	Ns	Ns	Ns	Ns	Ns	496.1	930.7
	N-P rate	Ns	10.53	13.20	Ns	Ns	Ns	995	405	503
	Rotation crops x N-P rate	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)		8.59	4.10	7.11	8.45	16.31	12.92	13.89	8.05	12.46

Recommended= 110/46 kg N-P₂O₅ ha⁻¹, Half recommended= 55/23 kg N-P₂O₅ ha⁻¹, Ns= non-significant

Table 4. Effects of rotation crops and N-P fertilizer rate on grain yield of maize.

Treatment	2001		2003		Mean		Rotation mean
	Half recommended	Recommended	Half recommended	Recommended	Half recommended	Recommended	
Niger seed	6228	7594	5488	6884	5858	7239	6549
Haricot bean	6484	8231	3263	4333	4874	6282	5578
Tef	5839	6569	3909	4858	4874	5713	5294
Mean	6184	7465	4220	5358	5202	6411	
Rotation crops	Ns		496.1				930.7
N-P rate	995		405		503		
CV (%)	13.89		8.05			12.46	

Campbell *et al.* (1992) reported accumulative enhancement of the N-supplying power of the soil in wheat-lentil rotation. The increase in total N following haricot bean helps to reduce the amount of N required to optimize maize yield. Organic carbon contents of the soil ranged from 1.96 to 2.45 % in 2000 and from 1.70 to 1.90 % in 2003 (Table 5 and 6) found in low range (FAO, 1990). This might be due to continuous cultivation of the field for the past three decades. Soil organic carbon contents declined regardless of inputs application for continuously cultivated land (Kapkiyai, 1996). Higher Organic carbon content next to before planting (1.98 %) was recorded from haricot bean field in 2000 and (1.90 %) in 2003 from field treated with recommended fertilizer following Niger seed (Table 5 and 6). Higher C:N was recorded from Niger seed field in both years followed by haricot bean (Table 5 and 6). Available P in Olsen and Bray II method ranged from 6.4 to 21 and 5.6 to 36 ppm and higher for preplant soil analysis compared to post harvest soil analysis result in 2000 (Table 5). In 2003, using Olsen procedure, available P ranged from

5.12 to 7.86 ppm (Table 6). This situation can be attributed to the high phosphorous fixing capacity of acid soil. The phosphorous content of the soil was found to be between moderate to adequate range for maize production (FAO, 1990). The exchangeable K, Ca, and Mg contents of the soil ranged from 0.21 to 0.41, 1.10 to 1.33 and 1.32 to 1.56 in 2000 and 1.24 to 2.55, 4.19 to 6.44 and 0.99 to 1.56 Meq 100 g of soil⁻¹ in 2003 (Table 5 and 6). The CEC of the soil ranged from 9.99 to 11.79 and 13 to 15 Meq 100 g of soil⁻¹ (Table 5 and 6) and location in the low range for maize production (FAO, 1990). The texture of the soil was sandy clay loam to clay (Table 5). Base saturation ranged from 24 to 34 and 41 to 78 % (Table 5 and 6). The preplant soil analysis results were higher than post harvest soil analysis for different nutrients. The relatively low soil nutrient concentrations were due to continuous monocropping and cultivation over the last three decades which is consistent with Wakene *et al.* (2001).

Table 5. Result of soil chemical and physical analysis before sowing and after harvesting of break crops in 2000.

Treatment	PH		T. N	O.C	C: N	Available P (ppm)		K	Ca	Mg
	H ₂ O	KCl	(%)	(%)		Olsen	Bray II	Meq 100 g soil ⁻¹		
Before sowing	5.2	4.2	0.17	2.45	15	21.0	36	0.41	1.33	1.56
Niger seed	5.5	3.9	0.13	1.96	15	7.2	8.0	0.28	1.18	1.48
Haricot bean	5.0	3.7	0.15	1.98	13	7.6	9.0	0.24	1.10	1.40
Tef	5.0	3.8	0.14	1.90	14	6.8	9.0	0.21	1.13	1.32
Continuous	5.0	4.9	0.17	1.96	12	6.4	5.60	0.28	1.31	1.56

T.N, total nitrogen; O.C, organic carbon; C.N, carbon nitrogen ratio

Table 5. Result of soil chemical and physical analysis before sowing and after harvesting of break crops in 2000...continued

Treatment	Soil texture				CEC Meq/100	Base Saturation	Exchange acidity
	Sandy (%)	Silt (%)	Clay (%)	Class			
Before sowing	44	14	42	C	9.99	34	0.29
Niger seed	38	14	48	C	9.99	31	0.78
Haricot bean	58	10	32	SCL	11.79	24	0.88
Tef	36	14	50	C	10.99	25	0.83
Continuous	38	14	48	C	11.59	28	0.53

3.6. Plant Tissue

Nitrogen contents of the leaves were significantly higher in rotation compared to continuous maize in 2001 (Table 7). In 2003, N contents of the leaves were higher in maize following Niger seed and haricot bean with half recommended N-P rates compared to continuous maize (Table 8). Nitrogen contents of the leaves ranged from 0.64 to 1.01 % and 0.40 to 0.55 %, respectively in 2001 and 2003 (Tables 7 and 8). A significant increase in N concentration in leaves occurred following crops compared to continuous cropping. An appreciably higher (1.01 %) N concentration resulted from maize following haricot bean (Table 7), indicating higher carry over effect of N following haricot bean. This indicates high residual N following haricot bean was available for maize. Thus, use of crop rotation improved nutrient uptake efficiency of maize. Phosphorous concentration of the leaves of

maize in rotation was higher, up to 240 and 140 ppm, in 2001 and 2003 than continuous maize except maize following tef in 2001 and maize after Niger seed in 2003 planted with half recommended fertilizer rate (Tables 7 and 8). The K concentration of the leaves was higher in continuous maize, except maize following tef with half recommended fertilizer rate (Table 7). Stalk N concentration was inconsistent across two years (Tables 7 and 8). Higher N concentration 0.88 and 0.48 % in 2001 and 2003 was recorded in maize following Niger seed and tef. P content of the stalk less or equivalent to continuous maize except maize following tef with recommended fertilizer rate in 2003 (Table 7 and 8). With the exception of maize following Niger seed and tef with recommended fertilizer rate, the other treatments had higher potassium in the stalk compared to continuous maize in 2001 (Table 7).

Table 6. Result of soil chemical analysis after harvesting of maize crops in 2003.

Rotation crops	N-P rate	P.H:	T.N	O.C	C: N	Available P	K	Ca	Mg	E.C	CEC	Base Saturation
		H ₂ O	(%)	(%)		(ppm)	Meq 100 g soil ⁻¹			Ds m ⁻¹	Meq100 ⁻¹	%
Niger seed	Half recommended	5.9	0.15	1.70	11	5.60	1.62	5.89	1.40	0.06	14	67
Niger seed	Recommended	5.9	0.15	1.90	13	6.48	1.56	5.14	1.32	0.07	15	55
Haricot bean	Half recommended	6.0	0.15	1.82	12	7.50	1.58	5.59	1.24	0.08	15	59
Haricot bean	Recommended	5.9	0.16	1.78	11	7.38	1.24	4.54	0.99	0.06	17	41
Tef	Half recommended	6.0	0.16	1.72	11	7.38	1.24	4.49	1.15	0.07	16	44
Tef	Recommended	5.9	0.15	1.70	11	7.86	1.59	4.19	1.07	0.06	15	47
Continuous	Recommended	6.0	0.18	1.78	10	6.52	2.55	5.69	1.56	0.06	13	78

Recommended = 110/46 kg N-P₂O₅ ha⁻¹, Half recommended = 55/23 kg N-P₂O₅ ha⁻¹

T.N, total nitrogen; O.C, organic carbon; C.N, carbon nitrogen ratio

Table 7. Maize tissue analysis (leave, stalk and grain) for primary nutrients in 2001.

Rotation crops	N-P fertilizer rate	Maize tissue analysis								
		Leaves			Stalk			Grain		
		N (%)	P (ppm)	K (ppm)	N (%)	P (ppm)	K (ppm)	N (%)	P (ppm)	K (ppm)
Niger seed	Half recommended	0.74	580	4900	0.88	150	18440	1.15	2390	4020
Niger seed	Recommended	0.95	630	4700	0.23	80	14490	1.27	2720	4630
Haricot bean	Half recommended	1.01	730	4890	0.30	130	17510	4.44	1880	3690
Haricot bean	Recommended	0.74	600	4830	0.25	160	19770	3.63	1590	3240
Tef	Half recommended	0.71	320	8040	0.46	120	17520	5.95	2200	4280
Tef	Recommended	0.74	590	4840	0.44	220	16780	1.17	2980	5340
Continuous	Recommended	0.64	490	5920	0.30	160	16940	1.00	2380	4260

Recommended = 110/46 kg N-P₂O₅ ha⁻¹, Half recommended = 55/23 kg N-P₂O₅ ha⁻¹

Maize grain nitrogen concentrations significantly increased in rotation compared to continuous cropping (Table 7). Maize grain N concentration in rotation ranged from 0.142 to 4.94 % (Table 7). Higher mean N grain concentration was recorded from maize following haricot bean followed by tef compared to Niger seed and continuous maize (Table 7). Application of higher N reduced N concentration in maize grain (Table 7). This might be due to the increase of N use efficiency of maize with higher application N fertilizer. Non-significant increase in maize grain P concentration occurred with maize following Niger seed with half recommended fertilizer but a significant increase was registered following Niger seed and tef with recommended fertilizer rate compared to continuous maize (Table 7). A Significant decrease in maize grain P concentration was achieved from maize following haricot bean with both fertilizers as compared to continuous maize (Table 7). Maize grain K concentration ranged from 1020 to 1080 (Table 7). With the except of maize following haricot bean, grain P and K concentration increased with additional increment of P application (Table 7). In general, the concentration of NPK in maize tissue and grain was higher with maize following break crops than continuous maize which agrees with the report of Copeland and Crookston (1992). Macronutrients (N,P

and K) accumulation in corn tissue at physiological maturity and grain yield were greater in rotation than corn grown in monoculture.

The results of economic analysis for N-P fertilizer rate and rotation crops are shown in (Tables 9 and 10). The highest net benefit of EB 13210 ha⁻¹ and marginal rate of return 177 % came from the application of recommended (110/46 kg N-P₂O₅ ha⁻¹) rate compared to the half recommended that was EB 11365 ha⁻¹ (Table 9). The values to cost ratio EB 10.92 and 6.34 per unit of investment was for half recommended and recommended N-P fertilizer rate. The result for rotation crops indicated that the highest net benefit of EB 15619 ha⁻¹ of maize was obtained from maize following Niger seed (Table 10). The second net benefit of EB 13304 ha⁻¹ was achieved from maize following haricot bean (Table 10). The net economic returns of maize following Niger seed, haricot bean and tef were EB 4965, 2650 and 1972 ha⁻¹ respectively, higher than continuous maize (Table 10). This indicates that rotating maize with oil crops and legumes gave better cereals. It was found that yield and economic return from the rotation crops were significantly higher than from continuous cropping. Rotating maize improved to a greater extent than adding inputs to continuous maize.

Table 8. Maize tissue analysis (leave and stalk) for primary nutrients in 2003.

Rotation crops	N-P fertilizer rate	Maize tissue analysis			
		Leaves		Stalk	
		N (%)	P (ppm)	N (%)	P (ppm)
Niger seed	Half recommended	0.31	420	0.31	260
Niger seed	Recommended	0.40	300	0.28	300
Haricot bean	Half recommended	0.34	260	0.36	280
Haricot bean	Recommended	0.55	380	0.28	160
Tef	Half recommended	0.60	360	0.23	200
Tef	Recommended	0.54	340	0.48	180
Continuous	Recommended	0.44	200	0.32	300

Recommended = 110/46 kg N-P₂O₅ ha⁻¹, Half recommended = 55/23 kg N-P₂O₅ ha⁻¹

Table 9. Partial budget and marginal rate of return analyses for N-P fertilizer rate on the mean grain yield of maize at Bako.

Items	N-P ₂ O ₅ fertilizer rate	
	100-50 kg ha ⁻¹	200-100 kg ha ⁻¹
Average yield (kg ha ⁻¹) maize	5202	6412
Adjusted yield (kg ha ⁻¹) maize	4681.8	5770.8
Gross field benefit of maize	12407	15293
Costs Urea (EB ha ⁻¹)	606	1212
Costs DAP (EB ha ⁻¹)	428.5	857
Fertilizer application cost (EB ha ⁻¹)	7.00	14.00
Total costs that vary (EB ha ⁻¹)	1041.5	2083
Net benefit	11365.5	13210
Values to cost ratio	10.92	6.34
Marginal rate of return (MRR)		177 %

Note: Grain price = EB 2.65 kg⁻¹, Seed price = EB 5 kg⁻¹, Labour cost = EB 7.00 /day Yield was down adjusted with 10% coefficient, Cost of Urea = EB 6.06 kg⁻¹ DAP = EB 8.57 kg⁻¹.

Table 10. Partial budget and marginal rate of return analyses for rotation crops on the mean grain yield of maize at Bako.

Items	Rotation crops			Continuous maize
	Niger seed	Haricot bean	Tef	
Average yield (kg ha ⁻¹) maize	6549	5578	5294	4467
Adjusted yield (kg ha ⁻¹) maize	5894.1	5020.2	4764.6	4020.3
Gross field benefit of maize	15619	13304	12626	10654
Net benefit	15619	13304	12626	10654

Note: Grain price = EB 2.65 kg⁻¹, Seed price = EB 5.00 kg⁻¹, Labour cost = EB 7.00 /day Yield was down adjusted with 10% coefficient

4. Conclusion

Maize grain yields increased significantly following rotation crops compared to continuous cropping. Primary nutrient (N, P and K) composition of the tissue and grain of maize increased following rotation crops. The maintenance and enhancement of soil fertility is possible through appropriate application of N-P rate and crop rotation. The use of crop rotation is the cheapest method of soil fertility replenishment for resource poor farmers. The result demonstrated the residual benefits of crop rotation with N-P fertilizer, enhancing the grain yields and fertility of the soil. Therefore, maize following Niger seed and haricot bean with recommended N-P fertilizer application is recommended for sustainable maize production in Bako area.

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