Fosu-Mensah and Mensah *Environ Syst Res (2016) 5:22*
DOI 10.1186/s40068-016-0073-2

Environmental Systems Research

RESEARCH Open Access

The effect of phosphorus and nitrogen fertilizers on grain yield, nutrient uptake and use efficiency of two maize (*Zea mays* L.) varieties under rain fed condition on Haplic Lixisol in the forest-savannah transition zone of Ghana

Benedicta Y. Fosu-Mensah[1,2*] and Michael Mensah[3]

Abstract

Background: Low soil fertility is recognized as the major constraint to food production and food security in Ghana. An important practice that restores some level of fertility is long fallow, however this is no longer practiced due to increased pressure on land for other purposes. This has resulted in decline in crop yields in areas (forest-savannah transition zone or Sub-humid Ghana) which are known to be one of the major food baskets for the country. The soils are generally poor and require mineral fertilizer to increase crop productivity. In order to increase food production and crop productivity, the use of mineral fertilizer is required other than the expansion of arable land. The aim of this paper is to assess the influence of Phosphorus and Nitrogen fertilizers on the yield of two maize varieties and nutrient use efficiency in the forest-savannah transition zone of Ghana.

Methods: Experimental data from two maize varieties (*Zea mays* L.) grown under four concentrations of nitrogen (N) and three concentrations of phosphorus (P) in the 2008 major and minor seasons at two sites in Ejura, Ghana, were used to assess the influence of P and N on the yield, nutrient uptake and use efficiency in the forest-savannah transition zone of Ghana.

Results: Analysis of variance showed a statistically significant effect of N and P on grain yield, total biomass, grain N uptake and apparent N recovery. Increasing N concentration significantly increased grain yield, grain N uptake and total dry matter production irrespective of application of P fertilizer. The application of P fertilizer increased N use efficiency with grain yield ranging from 918 (control) to 4953 kg ha^{-1} (N4P2) and 824 (control) to 4267 kg ha^{-1} (N4P2) for Obatanpa and Dorke maize, respectively. The two cultivars were significantly different from each other with higher grain yield produced by Obatanpa than Dorke. The application of inorganic P fertilizer increased the efficient utilization of inorganic N fertilizer by the plants in grain yield and total biomass production. Hence, P nutrition of soils is critical for the efficient use of inorganic N fertilizer in the area.

Conclusions: Inorganic fertilizer use in the study area was agronomically efficient, though generally more efficient at the Ejura farm site (Experiment 1 and 3) than the Agricultural College site (Experiment 2 and 4). Owing to the spatial variability in soil nutrients in the study area, site-specific fertilizer testing is needed to increase nutrient use efficiency and crop productivity. To improve the rate of fertilizer adoption and use by farmers, the government should subsidize the cost of fertilizer to make it affordable for farmers to purchase to increase crop productivity.

---

*Correspondence: yayramensah@staff.ug.edu.gh
[1] Institute for Environment and Sanitation Studies (IESS), University of Ghana, Legon, P. O. Box 209, Accra, Ghana
Full list of author information is available at the end of the article

Keywords: Maize, Use-efficiency, Nitrogen, Dorke, Phosphorus, Nutrient uptake, Obatanpa

Background

Poor soil fertility is recognized as the major constraint to food production and food security in Ghana. Most soils in Ghana are deficient in phosphorus (P) and nitrogen (N). Phosphorus, the second most widely limiting nutrient in soil after nitrogen (Balemi and Negisho 2012), is a critical macronutrient for plant growth; and in tropical agroecosystems soil, P deficiency is a major limitation to crop production (Mustonen et al. 2012). Research report indicate that <1 % of soil P is available for plant uptake (Stewart and Tiessen 1987) as a result of strong adsorption of phosphate by iron and aluminium oxides (Xavier et al. 2011). According to Sharma et al. (2011), phosphorus has a significant role in sustaining and building up soil fertility, especially under intensive system of agriculture. Thus, its deficiency becomes an important chemical factor restricting plant growth in soils. While N is the most limiting nutrient generally in soil, Delve et al. (2009) has shown that deficiency of soil P reduces the efficiency of N use by crops.

In order to increase crop production to feed the ever increasing population, the use of mineral fertilizer needs to be encouraged, especially, among the smallholder farmers who form the larger proportion of farmers in Ghana to improve soil fertility. Whereas mineral fertilizer application is important, it is also necessary to increase N use efficiency to make the use of mineral fertilizer cost effective and attractive to smallholder farmers. Farmers are sometimes reluctant to apply N fertilizer due to the low use efficiency, which translates into low yields. In Ghana, most farmers are unable to purchase mineral fertilizers to boost crop production due to the high cost (Fosu et al. 2004) and low capital of farmers. Thus, the need to increase fertilizer use efficiency is crucial to make it attractive to farmers.

Ejura, in the forest-savannah transition ecological zone is one of the major food producing areas in Ghana. Over the years, there has been a decline in the yields of crops due to continuous cropping on the same piece of land without the use of mineral fertilizer. The farming systems in Ghana, especially in the forest-savannah transition zone are predominantly low-input and mostly subsistence based production. As a result of the low input nature of the system, crop production particularly cereals is hampered by low concentration of soil nitrogen (N) and phosphorus (P), erratic and poorly distributed rainfall patterns (Bationo et al. 2003).

The low concentrations of soil N and P are threats to food security in the country, unless measures are taken to improve on soil fertility. As the population of the country grow, the demand for food especially maize, which is one of the most important cereals, will increase.

Unfortunately most farmers in this region do not apply mineral fertilizers especially P fertilizers hence, plants are not able to get the required nutrients for proper growth and grain production.

Over the years, farmers in the region used longer fallow to restore some level of fertility but this is no longer common as a result of increased pressure on land for other purposes. In order to be food secure, there is a need to increase crop productivity rather than expansion of land. Little has been reported on the response of improved maize varieties (Obatanpa and Dorke) to different rates of phosphorus and nitrogen fertilizers under rain fed condition. The aim of this paper is to assess the influence of P and N on the grain yield, nutrients uptake and use efficiency of Obatanpa and Dorke maize varieties in the forest-savannah transition of Ghana.

Methods

The study was conducted in Ejura, in the Sekyedumase District of the Ashanti Region of Ghana which is located in the southern fringes of the Volta Basin (Fig. 1). It has a slightly hilly terrain (150–250 m above sea level) and lies in the forest-savannah transition agro ecological zone, with the moist forest in the south and the Guinea savannah zone to the north. The region is bounded by latitude 7_220 N and longitude 1_210 W. This zone is characterized by a bimodal rainfall (major and minor seasonal rainfall) with mean annual rainfall of about 1400 mm. The soil in the study area was Haplic Lixisol (FAO classification). Haplic Lixisol is formed over weathered voltaian sandstone on middle-slope and gentle sloping topography. The soil is deep, well grained, and brown in color with humus-stained top soil overlapping a thick brown clayey sub-soil. These soil types have high sand content, acidic in nature and are generally low in nitrogen and organic carbon.

Experimental layout and design

Four experiments were conducted in Ejura during the major and minor seasons in 2008 at two different sites. Experimental plots of 6×5 m^2 were laid out in a randomized complete block design (RCBD) with three replicates, and two maize varieties (Obatanpa: a medium maturity variety; and Dorke: an early maturity variety) used as the test crop. Seeds were sown at a depth of about 5 cm and crop spacing was 75 cm between rows

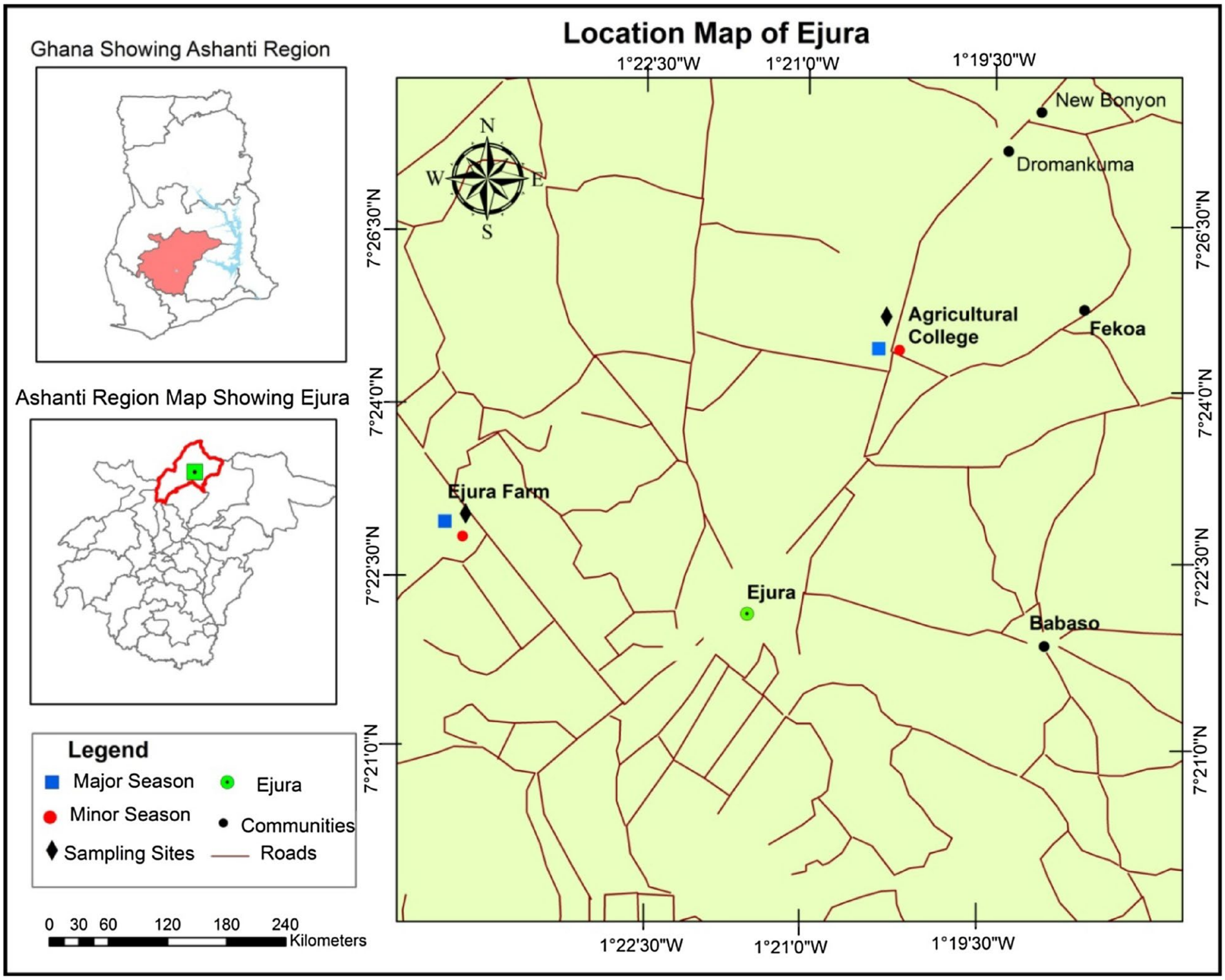

Fig. 1 Map showing the study area and experimental sites

and 40 cm within rows, with planting density of 6.7 m^2. Weeding was done manually with hoe to keep the fields free from weeds. Rainfall distribution and amount throughout the season were also monitored as shown in Fig. 2.

Three concentrations of P (0, 30 and 60 kg ha^{-1}) in the form of triple super phosphate and four concentrations of N (0, 40, 80, and 120 kg ha^{-1}) in the form of ammonium sulphate were applied in all experiments. The full rate of phosphorus and half the rate of N were applied 10 days after sowing in the form of triple super phosphate (P_2O_5) and ammonium sulphate, respectively. The other half of N was applied 45 days after sowing. During the major season, Obatanpa and Dorke maize varieties were planted on April 21 and 24 in Expt. 2 and Expt. 1, respectively. In the minor season, the sowing was done

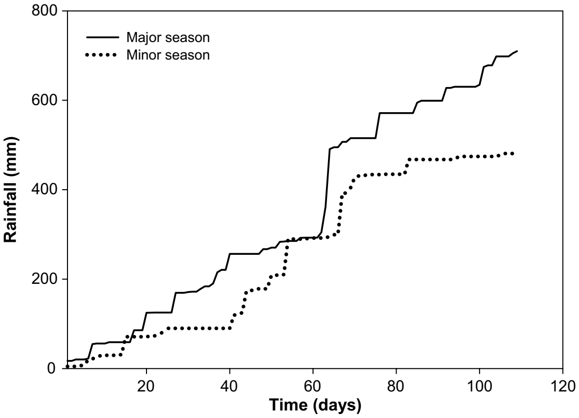

Fig. 2 Cumulative rainfalls during major and minor season in Ejura, Ghana, 2008

on August 8th and 9th in Expt. 3 and Expt. 4, respectively. Experiment 1 and 3 (Expt. 1 and Expt. 3) were located at Ejura farm and Experiment 2 and 4 (Expt. 2 and Expt. 4) at the Agricultural College. Soils were sampled before establishment of the Experiment (0–100 cm at 15 cm interval) using soil auger. The sampled soils were air dried and passed through a 2 mm sieve. The soil samples were analysed for soil pH, soil organic carbon, calcium, total nitrogen, available phosphorus, potassium among others.

The pH of soil was determined using the 1:1 method, where 1:1 proportions of soil and deionized water suspension was stirred vigorously for 20 min. The content was left to stand for 30 min before measurement with pH electrode (McKeague 1978; McLean 1982) using microprocessor pH Meter (Van London Phoenix Electrodes, USA).

Similarly, soil organic carbon (SOC) was determined using the modified procedure by Walkley and Black (1934) as described by Nelson and Sommers (1982). In order to oxidized organic carbon, a known concentration of potassium dichromate (0.166 M) solution was added in excess. The amount of soil organic matter (SOM) was determined by multiplying the percentage C by the factor 1.724 (Walkley and Black 1934).

Soil total nitrogen was determined using the micro Kjeldahl distillation and titration method (Bremner and Mulvaney 1982). A 1 g soil sample was weighed into a digestion flask, 5 ml concentrated sulphuric acid and few drops of 30 % hydrogen peroxide were added with selenium to serve as catalyst. The entire content was then digested. The use of this method converts organic nitrogen to ammonium sulphate and the resultant solution was made alkaline by the addition of 5 ml of 40 % sodium hydroxide and ammonia distilled into 2 % boric acid and titrated with standard hydrochloric acid.

The available soil P was determined using a Pye Unicom spectrophotometer at 880 nm wavelength in absorbance after extraction with Bray P-1 extractant and molybdate/ascorbic acid reduction. The Bray P-1 extractant was made up of 0.03 M NH_4F and 0.25 M HCl (Bray and Kurtz 1945). To determine exchangeable Ca and Mg, 10 ml of the extract was transferred to an Erlenmeyer flask and 5 ml of an ammonium chloride and ammonium hydroxide buffer solution was added, followed by addition of 1 ml triethanolamine. A few drops of potassium cyanide and Eriochrome Black T solutions were then added. The mixture was then titrated with 0.02 M EDTA solution from a red to a blue end point.

Statistical analysis

The general linear model (GLM) analysis of variance (ANOVA) were used to compare gain yield, grain nutrient uptake, and total biomass data from the different treatments and also between the varieties using SPSS version 17. The Tukey test for pairwise comparison of means was used to identify significant differences between the treatments.

Results and discussion

The results of chemical and physical analyses of the soil at the experimental sites in 2008 are presented in Tables 1 and 2. Data in Tables 1 and 2 indicate that soils at these sites are generally acidic at Agricultural College site than at Ejura farm. The recorded total N value in the top 15 cm layer was low (0.13 mg g^{-1} for Ejura farm sites and 0.03 mg g^{-1} at Agricultural College). Plant available P can be rated as medium and K as rather high according to Page et al. (1982). Similarly, the percentage organic carbon (1.1 and 0.36) is rated very low according to Landon (1996).

The low pH value recorded at the experimental sites could be attributed to the number of acidic cations present due to the leaching of basic cations. A similar low value was reported by Arthur (2009) for soil in Kwadaso, Kumasi, Ghana. Nitrogen is one of the most essential components of organic matter. The decomposition of organic matter leads to the release of some nutrients including N. The low amount of total soil N was as a result of the low SOC, which is due to the lack of applied crop residues to fields. In the region, crop residues are either burnt to make way for land preparation for the next crop or eaten by livestock. Crop residues and farmyard manure are reported to increase SOC (Kpongor 2007). Low extractable P values indicate deficiencies (Landon 1996) in the study area.

Effect of N and P on days to 50 % tasseling and days to maturity

Days to 50 % tasseling

The effect of site difference on days to 50 % tasseling was statistically significant ($p < 0.01$) with an average of 1 day early tasseling at the Ejura farm sites (Expt. 1 and 3) than at Agricultural college (Expt. 2 and 4) for both seasons, possibly reflecting the slower growth on the more acidic soil. Seasonal effect (Expt. 1 vs. 3) showed a slower development of crop by delaying days to 50 % tasseling by an average of 2 days during the minor season (i.e. 57 days) compared to the major season (i.e. 55 days) for Obatanpa. The same number of day's difference (2 days) were observed in Dorke variety (i.e. 52 vs. 54) for seasonal difference.

There was a statistically significant ($p < 0.01$) influence of varieties, P and N on days to 50 % tasseling in all four experiments. Obatanpa variety took more days (i.e. 56 days) to tassel compared to the Dorke variety (i.e. 53 days). The number of days to tasseling significantly

Table 1 Characteristics of Haplic Lixisol at Ejura farm in 2008 wet season

Soil parameters	Soil depth (cm)						
	0–15	15–30	30–45	45–60	60–75	75–90	90–100
Total N (mg g^{-1})	0.13	0.08	0.03	0.04	0.03	0.02	0.03
Available P (mg kg^{-1})	12.70	6.54	3.43	2.04	1.72	1.5	0.91
Available K (mg kg^{-1})	180	130	100	120	94	84	73
pH	5.05	5.61	5.71	5.78	5.86	6.03	6.12
Ca (cmol (+) kg^{-1})	4.2	5.0	4.3	3.9	3.8	3.7	3.7
Mg (cmol (+) kg^{-1})	1.8	1.6	1.4	1.4	1.6	1.9	1.2
ECEC (cmol (+) kg^{-1})	6.5	8.2	5.3	5.7	6.3	6.6	6.1
K (cmol (+) kg^{-1})	0.3	0.4	0.3	0.3	0.3	0.3	0.2
Organic C (%)	1.1	0.7	0.5	0.5	0.4	0.4	0.3
BS (%)	96.4	98.4	97.6	97.7	98.3	98.4	98.4
Bulk density (g cm^{-3})	1.50	1.55	1.54	1.54	1.44	1.50	1.40
Sand (%)	62.7	60.5	59.8	45.9	34.1	29.5	29.4
Silt (%)	33.2	33.4	33.1	37.5	38.8	42.5	41.5
Clay (%)	4.1	6.1	7.1	16.6	27.1	27.1	29.1

Table 2 Characteristics of Haplic Lixisol at Agricultural College in Ejura during the major season, 2008

Soil parameters	Soil depth (cm)						
	0–15	15–30	30–45	45–60	60–75	75–90	90–100
Total N (mg g^{-1})	0.03	0.03	0.02	0.02	0.02	0.02	0.03
Available P (mg kg^{-1})	9.4	4.8	2.3	1.8	1.4	1.1	1.1
Available K (mg kg^{-1})	85	85	85	89	107	101	132
pH	4.75	4.73	4.71	4.76	4.22	4.07	4.07
Ca (cmol (+) kg^{-1})	0.5	0.7	0.7	1.1	2.0	1.9	2.1
Mg (cmol (+) kg^{-1})	0.3	0.3	0.3	0.9	1.2	1.1	0.8
ECEC (cmol (+) kg^{-1})	1.7	2.0	1.6	2.7	4.3	4.3	4.3
K (cmol (+) kg^{-1})	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Organic C (%)	0.58	0.55	0.51	0.46	0.42	0.38	0.34
BS (%)	59.9	54.4	59.9	89.1	70.3	70.9	70.4
Bulk density (g cm^{-3})	1.63	1.61	1.63	1.64	1.54	1.50	1.45
Sand (%)	77.8	76.2	74.8	64.2	52.2	51.6	52.5
Silt (%)	18.1	20.7	22.1	29.7	30.8	32.3	30.4
Clay (%)	4.1	3.1	3.1	6.1	17.1	16.1	17.1

($p < 0.01$) increased by an average of 3 days with increased N stress in all experiments. This indicates that maize development and phenology are influenced by N concentration in the soil. The effect of P was similar, delaying tasseling by 1 day when inadequately supplied. No interactive effects of N and P were observed for days to 50 % tasseling, except in Expt. 3. There was early tasseling in Expt. 1 compared to the others. The early tasseling of the maize crop in Expt. 1 compared to the other experiments is attributed to the soil at the location, which was relatively fertile. Similar observations were reported for silking in maize in the semi-arid region of Nigeria by Gungula et al. (2003), tasseling of maize in the transition zone in Ghana by Adiku et al. (2009), flowering in sorghum in semi-arid region of Ghana by Kpongor (2007), and for tasseling in maize across arid to semi-arid regions of Pakistan by Khaliq (2008). The differences in number of days to tasseling between the varieties at a particular N rate suggest that the effect of N stress on phenology differs among varieties even when they are adapted to the same ecological zone (Gungula et al. 2003).

Days to maturity

There was no significant ($p > 0.05$) sites or seasonal effect on days to maturity. However, plants took on the average 1 more day to mature during the minor season (Expt. 3) (i.e. 99.2 days) compared to the major season (Expt. 1) (i.e. 98.4 days) for Obatanpa maize variety. The effect of varietal differences on number of days to maturity was statistically significant ($p < 0.01$) in all experiments, with Obatanpa taking on the average more days (i.e. 105.4 days) to mature compared to Dorke (i.e. 93.4 days). The application of N significantly ($p < 0.01$) influenced days to maturity. There was no significant difference between days to maturity at different P concentrations.

Similar trends were observed for the Dorke variety where increase in N concentration significantly ($p < 0.01$) decreased days to maturity. Plants in Expt. 1 matured earlier (i.e. 91 to 93 days) followed by those in Expt. 2 (i.e. 92 to 94 days) with Expt. 4 showing the highest number of days to maturity (i.e. 93 to 96 days). The higher number of days taken by plant to reach maturity at the Agricultural college site (Expt. 2 and 4) is probably due to the low level of initial soil nutrient and organic matter in this site.

Maize dry matter accumulation at 55 days after sowing

Figures 3 and 4 present the summary results of Obatanpa and Dorke maize dry matter accumulation at 55 days after sowing (DAS) at all sites. There was statistically significant ($p < 0.01$) site difference in dry matter (DM) production at 55 DAS, with 12.4 % higher DM at Ejura farm sites (Expt. 1 and 3) compared to Agricultural College site (Expt. 2 and 4).

Dry matter accumulation during the major season (Expt. 1) was significantly ($p < 0.01$) higher by 14 % compared to the minor season (Expt. 3). The significant seasonal difference in dry matter (DM) accumulation at 55 DAS is attributed to the quantity and distribution of rainfall between the two seasons (Fig. 1). ANOVA showed significant varietal difference, with Dorke producing a higher average biomass (5.9 %) than Obatanpa, except in Expt. 4. However, the varieties reacted differently to the application of N in the case of Expt. 4, and also to P, with Dorke being more responsive to N than Obatanpa.

Generally, the application of N fertilizer significantly ($p < 0.01$) increased DM accumulation (Figs. 3, 4). There was significant increase ($p < 0.01$) in DM when N was applied irrespective of the application of P fertilizer. Statistically, significant ($p < 0.01$) interactive effects of N and P mineral fertilizer on DM accumulation were observed. The application of inorganic N fertilizer significantly ($p < 0.01$) increased aboveground DM by 18.3, 29.3 and 33.6 % at N concentrations of 40, 80 and 120 kg ha^{-1} respectively over the control. Significant differences in DM accumulation at 55 DAS were observed between 0, 30 and 60 kg P ha^{-1} at all levels of N with the exception of the control (0 kg N ha^{-1}). There was, however, no significant difference in DM response to P beyond 30 kg P ha^{-1}.

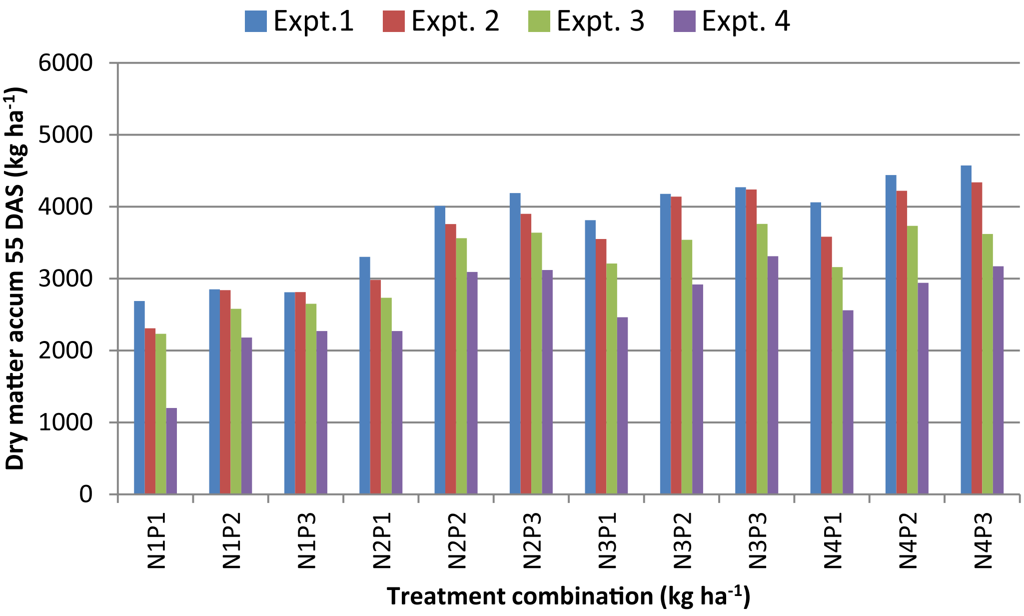

Fig. 3 Effect of nitrogen and phosphorus fertilizer on Obatanpa maize dry matter accumulation 55 days after sowing (DAS) at Ejura during the major and minor season, 2008. N1, N2, N3 and N4 indicate 0, 40, 80 and 120 kg N ha^{-1}; P1, P2 and P3 indicate 0, 30 and 60 kg P ha^{-1}

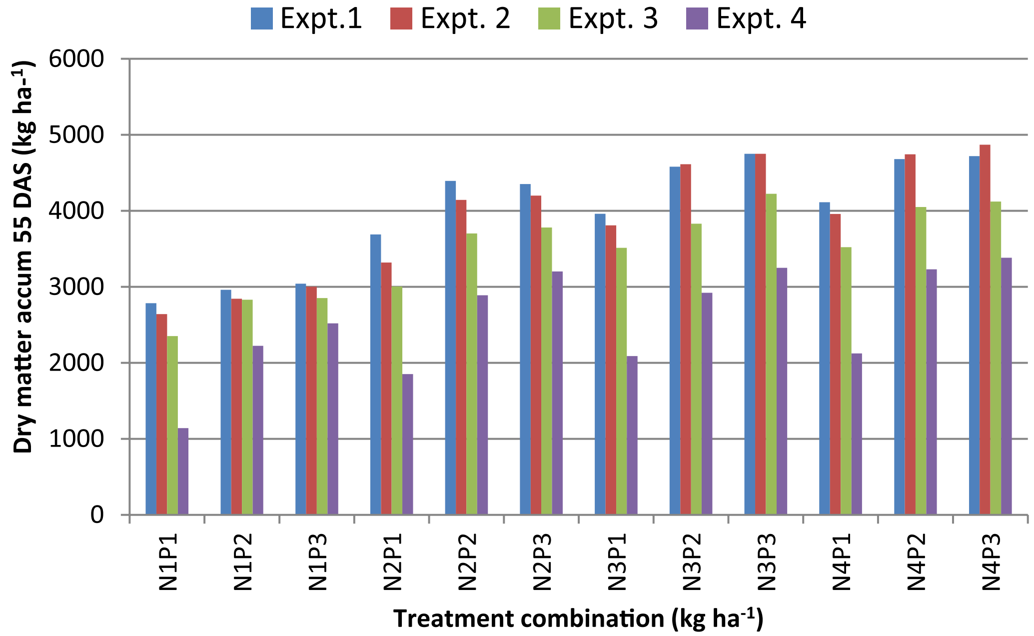

Fig. 4 Effect of nitrogen and phosphorus fertilizer on Dorke maize dry matter accumulation 55 days after sowing at Ejura during the major and minor season, 2008. (for legend, see Fig. 3)

Thus, beyond 30 kg P ha^{-1}, other factors (other soil nutrients or environmental factors or both) were limiting DM production.

Similar trends were observed for Dorke maize variety for DM accumulation at 55 DAS. Nitrogen and P mineral fertilizers significantly ($p < 0.01$) increased DM accumulation (Fig. 4). There was significant increase in DM accumulation at 55 DAS when P was applied at all levels of N with the exception of the control (0 kg N ha^{-1}). There was, however, no significant response of DM to P beyond 30 kg P ha^{-1}.

The difference in DM accumulation between the two varieties at 55 DAS is attributed to the differences in time to complete the life cycle. Dorke has a shorter life cycle and might have resulted in faster growth rate than Obatanpa variety.

Nitrogen uptake by maize plants at 55 days after sowing

Tables 3 and 4 present the results of N uptake of Obatanpa and Dorke maize varieties at 55 DAS. The influence of site difference on plants N uptake at 55 DAS was statistically significant ($p < 0.01$), with the Ejura farm site (Expt. 1 and 3) having a higher average N uptake (65 kg ha^{-1}) than the Agricultural College site (Expt. 2 and 4) which had an average N uptake of 57 kg ha^{-1}. Seasonal difference significantly ($p < 0.\ 01$) influenced N uptake at 55 DAS. During the major season (Expt. 1) maize plant N uptake was higher by 16.6 % than the minor season (Expt. 3). The ANOVA showed a statistically significant ($p < 0.01$) varietal, N and P effect on biomass N uptake at 55 DAS in all experiments. Higher N levels (3.3 %) were found in Dorke than in Obatanpa variety.

Nitrogen uptake by plants showed a similar trend as in DM production. Nitrogen and P and their positive interaction significantly increased N uptake at all concentrations of N in the Obatanpa variety (Table 3). Generally, Expt. 1 had the highest N uptake ranging from 39 to 94 kg ha^{-1} compared to the others. The application of 60 kg P ha^{-1} increased N uptake by 5.7, 11.3, 18.1 and 14.6 % over those without P fertilizer application for 0, 40, 80 and 120 kg N ha^{-1} respectively.

The same trends were obtained for the Dorke maize variety (Table 4). Experiment 4 had the lowest N uptake reflecting the poorer quality of the soil. There was, however, no interactive effect of N and P. Nitrogen uptake ranged from 18 (N1P1) to 67 kg ha^{-1} (N3P3 and N4P3) for Dorke maize variety.

The difference in N uptake at the different sites is attributed to difference in SOM and soil structure. The Ejura farm site had relatively higher SOM, and might have retained more moisture for a longer period than the soil at the Agricultural College. The higher organic matter might have made more nutrients available to the plants than at the Agricultural College site. The difference in N uptake between the two seasons may be

Table 3 Effect of nitrogen and phosphorus fertilizer on aboveground biomass N uptake of Obatampa maize variety biomass 55 DAS at Ejura during the major and minor season, 2008

Treatment combination	Biomass N uptake (kg ha^{-1})					
	N (kg ha^{-1})	P (kg ha^{-1})	Expt. 1	Expt. 2	Expt. 3	Expt. 4
N1P1	0	0	39	33	33	18
N1P2	0	30	41	35	36	30
N1P3	0	60	41	35	36	31
N2P1	40	0	65	55	50	37
N2P2	40	30	69	59	65	57
N2P3	40	60	73	60	66	58
N3P1	80	0	76	77	59	45
N3P2	80	30	90	81	78	58
N3P3	80	60	93	81	79	67
N4P1	120	0	81	76	60	49
N4P2	120	30	93	94	76	62
N4P3	120	60	94	94	76	67
Mean			71	65	59	48
Effects			**F-probability**			
N			**	**	**	**
P			**	**	**	**
N * P			**	**	**	**

Expt. 1 Ejura farm major season, *Expt. 2* Agric College major season, *Expt. 3* Ejura farm minor, *Expt. 4* Agric College minor season, *NS* non-significant

*, ** Significant at 0.05 and 0.01, respectively

Table 4 Effect of nitrogen and phosphorus fertilizer on aboveground biomass N uptake of Dorke maize variety biomass 55 DAS at Ejura during the major and minor season, 2008

Treatment combination	Biomass N uptake (kg ha^{-1})					
	N (kg ha^{-1})	P (kg ha^{-1})	Expt. 1	Expt. 2	Expt. 3	Expt. 4
N1P1	0	0	40	33	35	18
N1P2	0	30	41	33	37	31
N1P3	0	60	42	34	37	33
N2P1	40	0	67	58	56	34
N2P2	40	30	76	63	65	51
N2P3	40	60	76	62	66	56
N3P1	80	0	83	74	65	39
N3P2	80	30	98	85	82	57
N3P3	80	60	97	86	83	64
N4P1	120	0	86	83	67	40
N4P2	120	30	99	99	82	63
N4P3	120	60	99	100	83	68
Mean			75	68	63	46
Effects			**F-probability**			
N			**	**	**	**
P			**	**	**	**
N * P			**	**	**	**

Expt. 1 Ejura farm major season, *Expt. 2* Agric College major season, *Expt. 3* Ejura farm minor, *Expt. 4* Agric College minor season, *NS* non-significant

*, ** Significant at 0.05 and 0.01, respectively

attributed to the quantity and distribution of rainfall between the two seasons. There was a higher quantity of rainfall during the major season than during the minor season (Fig. 2), which might have led to higher N uptake during the major season than the minor season.

Phosphorus uptake by maize plants at 55 days after sowing (DAS)

There was a statistically significant ($p < 0.01$) site difference on biomass P uptake at 55 DAS, with a higher average value (5 kg ha^{-1}) of P uptake at the Ejura farm site (Expts. 1 and 3) than Agricultural College (Expts. 2 and 4) which had an average value of 4 kg ha^{-1}. The seasonal difference on P uptake of biomass at 55 DAS was statistically significant ($p < 0.01$). There was higher P uptake (5 kg ha^{-1}) on average during the major season (Expt. 1) than during the minor season (4 kg ha^{-1}), representing 16.4 % increase in P uptake over the minor season. ANOVA showed that there was only a significant difference in P uptake between the two varieties in Expt. 4.

Phosphorus uptake by both varieties was influenced by the application of N and P. There was, however a positive interaction of N and P only during the major season (Expts. 1 and 2). There was no significant difference in P uptake between 30 and 60 kg P ha^{-1} at all levels of N except in Expt. 4. In Expt. 1, P uptake in Obatanpa ranged from 4 kg ha^{-1} (N1P1) to 7 kg ha^{-1} (N4P3) while in Expt. 2 values ranged from 3 kg ha^{-1} (N1P1) to 6 kg ha^{-1} (N2P2, N2P3, N3P2, N3P3, N4P2 and N4P3). Experiment 4 had the lowest P uptake with values ranging from 1 to 4 kg ha^{-1}.

Similar trends were observed in P uptake for Dorke variety at 55 DAS. In Expt. 1, P uptake ranged from 4 kg ha^{-1} (N1P1) to 7 kg ha^{-1} (N4P3) while 3 kg ha^{-1} (N1P1) to 7 kg ha^{-1} (N4P3) was observed in Expt. 2. Experiment 4 had the lowest P uptake of 1.3 (N1P1) to 4 kg ha^{-1} (N2P3).

Grain yield

Figures 5 and 6 present the results of yield response of Obatanpa and Dorke maize verities to N and P fertilizer application. Generally, the application of N fertilizer significantly ($p < 0.01$) increased grain yield of Obatanpa maize up to 80 kg N ha^{-1} (Fig. 5). There was no significant increase in grain yield beyond 80 kg N ha^{-1} if there was no P application. During the major season at Ejura farm (Expt. 1), grain yield responded positively to N application, with yields ranging from 1623 kg ha^{-1} in N1P1 (control) to a maximum yield of 4953 kg ha^{-1} in N4P2 (120 kg N ha^{-1} and 30 kg P ha^{-1}). There was significant increase ($p < 0.01$) in grain yield when N was applied irrespective of the application of P fertilizer. However, there was no significant response to P beyond 30 kg P ha^{-1}. This signifies that beyond 30 kg P ha^{-1}, there are other factors (other soil nutrients and or environmental factors) limiting crop yield. Fosu-Mensah (2012) reported increased variability in grain yield of maize as a result of increased variability of rainfall. This means that crop

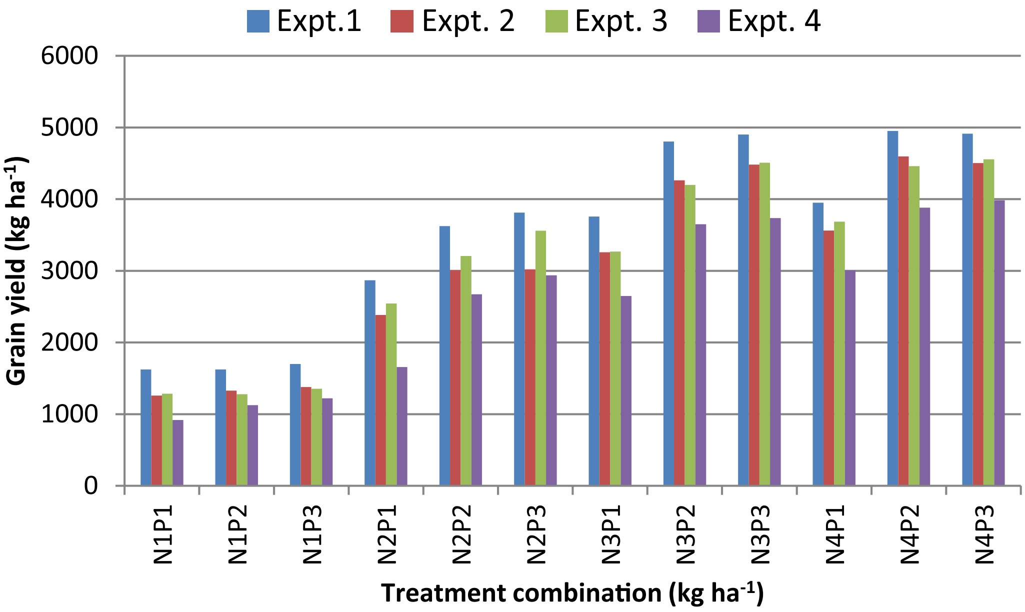

Fig. 5 Effect of nitrogen and phosphorus fertilizer on Obatanpa maize grain yield at Ejura during the major and minor season, 2008 (for legend, see Fig. 3)

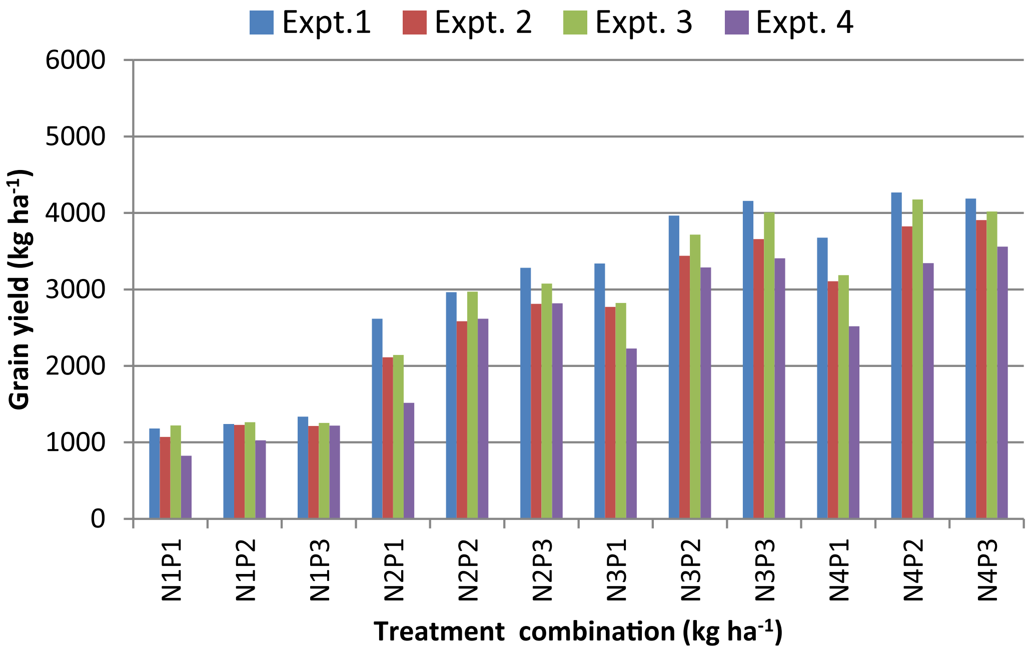

Fig. 6 Effect of nitrogen and phosphorus fertilizer on Dorke grain yield at Ejura during the major and minor season 2008. (for legend, see Fig. 3)

yield and nutrients uptake are influenced by rainfall in a moisture stress condition. Significant ($p < 0.01$) interactive effects of N and P mineral fertilizer on grain yield were observed. In Expt. 2, N and P significantly increased ($p < 0.01$) grain yields at all concentrations of N. The positive interactive effect of N and P was also statistically significant ($p < 0.01$). Application of N fertilizer increased grain yields ranging from 1258 in N1P1 to 4597 kg ha^{-1} in N4P2 (Fig. 5). Similar trends were observed in Expt. 3 and 4, where grain yields ranged from 1277 kg ha^{-1} in N1P2, to a maximum of 4557 kg ha^{-1} in N4P3 in Experiment 3 and from 918 in N1P1 to 3985 kg ha^{-1} in N4P3 in Experiment 4.

Similarly, in the Dorke variety, N and P and their interactive effect significantly increased grain yield at all concentrations of N (Fig. 6). Grain yields ranged from 824 kg ha^{-1} in the control (Expt. 4) during the minor season to a maximum value of 4267 kg ha^{-1} in N4P3 (Expt. 1) during the major season. The application of 30 kg P ha^{-1} increased grain yields by an average of 21 % in Obatanpa and 23 % in Dorke. Nitrogen and P and their combined effect significantly influenced grain yield of Dorke. Yields on the Ejura farm site (Expt. 1 and 3) were generally higher than those at the Agricultural College (Expt. 2 and 4). This difference was more pronounced during the minor season, which was probably due to the difference in SOM and soil water retention which was relatively higher at the Ejura farm site than at Agricultural College.

Similar findings have been reported by Kpongor (2007), Arthur (2009) and Adiku et al. (2009). The influence of P nutrition on the growth of maize in Kenya was reported by Delve et al. (2009), sorghum in semi-arid region in Ghana by MacCarthy et al. (2009) and in wheat in India by Saha et al. (2014). In this study, N was the most limiting soil nutrient as it is required in larger amounts than any other nutrient. The low amount of soil N was as a result of the low SOC, which is due to partial or total removal of crop residues after harvest. Limited availability of extractable P reduced N use efficiency of plants. However, given the limited resource (mineral fertilizer) availability, farmers go in for N fertilizers as its return is higher than that of P (MacCarthy et al. 2009).

Grain N uptake

Studies on N uptake further support the importance of N and P fertilizer for N uptake and use efficiency. In this study, P and N uptake significantly increased with N and P fertilization indicating increased availability or accessibility of these nutrients in the soil with application of mineral fertilizer.

Similarly, the application of N fertilizer significantly ($p < 0.01$) increased grain N uptake of Obatanpa maize. Figures 7 and 8 present the results of grain N uptake of Obatanpa and Dorke maize varieties during the major and minor seasons, respectively. During the major season at Ejura farm site (Expt. 1), Obatanpa grain N uptake

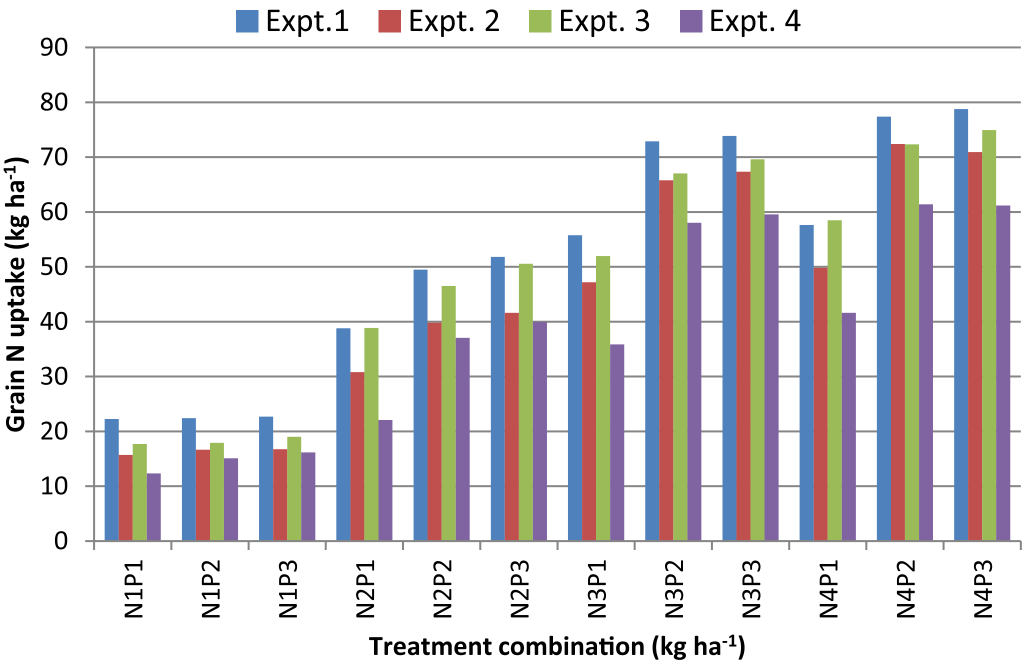

Fig. 7 Effect of nitrogen and phosphorus fertilizer on Obatanpa maize grain N uptake at harvest at Ejura during the major and minor season, 2008 (for legend, see Fig. 3)

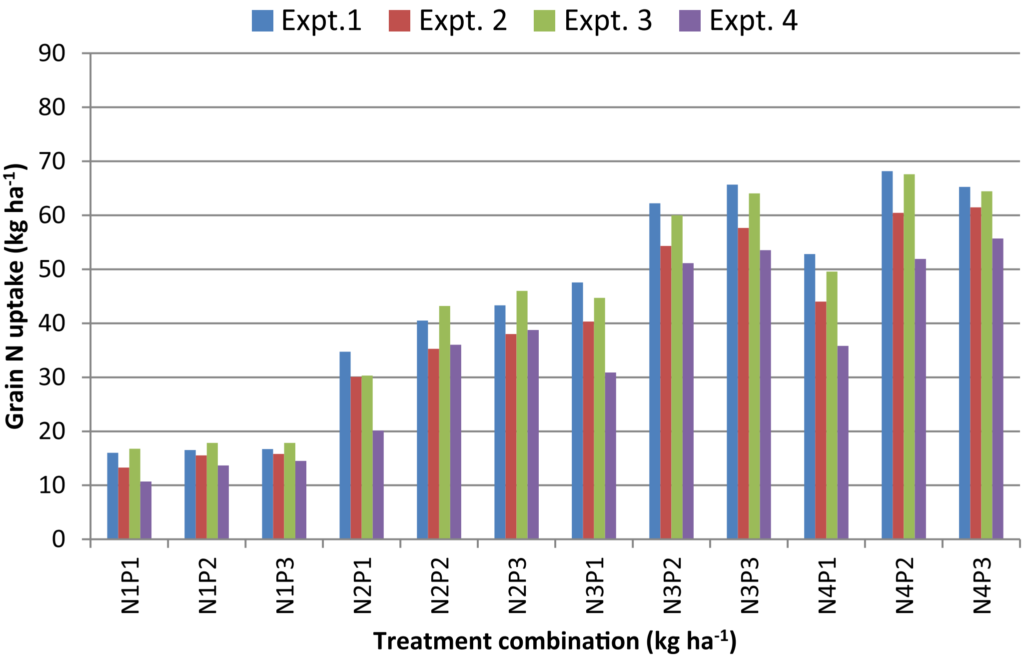

Fig. 8 Effect of nitrogen and phosphorus fertilizer on Dorke maize grain N uptake at harvest at Ejura during the major and minor season, 2008 (for legend, see Fig. 3)

responded positively to N application, with N uptake ranging from 22 kg ha^{-1} in N1P1 (control) to a maximum of 79 kg ha^{-1} in N4P3 (120 kg N ha^{-1} and 60 kg P ha^{-1}). There was significant increase ($p < 0.01$) in grain N uptake when N fertilizer was applied irrespective of the application of P fertilizer. However, there was no significant response to P fertilizer beyond 30 kg P ha^{-1}. Statistically, significant ($p < 0.01$) interactive effects of N and P mineral fertilizer on grain N uptake were also observed. Similarly, in Expt. 2, N and P significantly increased ($p < 0.01$) grain N uptake at all concentrations of N. The interactive effect of N and P was also statistically significant ($p < 0.01$). Application of N fertilizer increased grain N up take ranging from 16 kg N ha^{-1} in N1P1 to 72 kg ha^{-1} in N4P3 (Fig. 7). Similar trends were observed in Expt. 3 and 4 where grain N uptake ranged from 18 kg ha^{-1} in N1P2 and N1P3, to a maximum of 75 kg ha^{-1} in N4P3 in Expt. 3 and 12 kg ha^{-1} in N1P1 to 61 kg ha^{-1} in N4P2 and N4P3 in Expt. 4.

Similarly, trends were observed in the Dorke variety (Fig. 8) where N and P and their interactive effect significantly increased grain N uptake at all concentrations of N. Grain N uptake ranged from 11 kg ha^{-1} in the control (Expt. 4) during the minor season to a maximum value of 68 kg ha^{-1} in N4P2 (Expt. 1 and 3) during the major and minor season respectively.

The significant interactive effect of N and P on grain N uptake is an indication of the poor availability of these nutrients in the soil. With the application of 30 kg P ha^{-1}, grain N uptake was increased by more than 20 %. This translated into higher yields which made it attractive to apply P fertilizer. The combination of 30 kg P ha^{-1} and 40 kg N ha^{-1} produced more grain than 80 kg N ha^{-1} without P application. This result is in line with the findings of Akinnifesi et al. (2007) and Khaliq (2008). However, excessive rainfall will increase N loss through leaching and denitrification, and reduce N uptake leading to low yield. Excess rain will also reduce P uptake as a result of water logging, restricted root growth and root respiration. Similarly, low rainfall will restrict root growth and reduce P availability and uptake as well as N uptake. These effects will be exacerbated under climate change when there is excessive rain leading to flooding or low rainfall leading to drought.

Grain P uptake at harvest

Grain P uptake at final harvest in all experiments for Obatanpa is presented in Table 5. The ANOVA showed a statistically significant site difference ($p < 0.01$) on grain P uptake, with higher grain P uptake at the Ejura farm site (23.3 %) than at Agricultural College. Varietal difference on grain P uptake was also statistically significant ($p < 0.01$), with higher P uptake in Obatanpa (10.5 %) than Dorke variety. Similarly, seasonal difference on grain P uptake was also statistically significant ($p < 0.01$), with 14 % higher uptake during the major season than during the minor season. Generally, grain P uptake was low. The application of N and P and their interactive effect significantly ($p < 0.01$) increased P grain uptake. In Expt. 1, grain P uptake in Obatanpa ranged from 4 kg ha^{-1} in the control to 17 kg ha^{-1} in N4P3, representing 74 % increase. In Expt. 2, values ranged from 3 kg ha^{-1} in the control to 13 kg ha^{-1} (N3P3 and N4P3), representing a 78 % increase. Experiment 4 had the lowest grain P uptake, with values ranging from 2 to 12 kg ha^{-1}, while Expt. 3 had values ranging from 3 kg ha^{-1} (N1P1) to 15 kg ha^{-1} (TN4P3), representing an 83 % increase over the control (N1P1).

In addition, nitrogen and P significantly ($p < 0.01$) increased grain P uptake in Dorke variety. There was, however, no significant response of P beyond 30 kg ha^{-1}, except in Experiment 4, reflecting the low level of extractable P at this site.

On the average, about 65 % of the total P uptake in the maize was found in the grain. This has great implications for P export and soil P depletion, as the grain is removed for consumption, thus, removing a large fraction of the P taken up by the crop. A similar observation was reported for maize and cover-crop intercropping in the semi-arid region of Ghana by Fosu (1999). The higher P uptake is also reflected in the grain yield, which is very important to the farmer. In this study, P uptake by grain was significantly ($p < 0.01$) influenced by the application of N and P fertilizer at three concentrations of N, but there was no effect of N and P beyond 80 kg N ha^{-1} if there was no P application. The high interactive effect of N and P on P uptake is an indication of the relatively poor accessibility of soil P which improved with greater soils exploitation due to better root growth. The low P uptake in the treatments without P fertilizer application, which led to low grain yields, is attributed to soil P below the critical value.

Total biomass accumulation at harvest

Figures 9 and 10 present the results of total biomass production at harvest during major and minor season for Obatanpa and Dorke varieties. The influence of N and P and their combined effect significantly ($p < 0.01$) increased total dry matter (TDM) production at all concentrations of N for both varieties of maize. All treatments in all experiments produced higher TDM than the control. Averagely, Obatanpa produced 9.3 % (751 kg ha^{-1}) more TDM than Dorke. Similarly, total biomass production (8230 kg ha^{-1}) at the Ejura farm site (Expts. 1 and 3) was statistically significantly ($p < 0.01$) higher than the Agricultural College site (Expt. 2 and 4).

In Obatanpa, the trend of total biomass production was similar to grain yield. Total biomass yield ranged from a minimum of 4846 kg ha^{-1} (N1P1) to a maximum

Table 5 Effect of nitrogen and phosphorus fertilizer on Obatanpa maize grain P uptake at harvest at Ejura during the major and minor season, 2008

Treatment combination	Grain P uptake (kg ha^{-1})					
	N (kg ha^{-1})	P (kg ha^{-1})	Expt. 1	Expt. 2	Expt. 3	Expt. 4
N1P1	0	0	4	3	3	2
N1P2	0	30	6	4	4	3
N1P3	0	60	5	3	4	4
N2P1	40	0	6	4	5	3
N2P2	40	30	11	9	9	6
N2P3	40	60	12	9	10	8
N3P1	80	0	7	4	5	4
N3P2	80	30	15	12	13	10
N3P3	80	60	16	13	14	11
N4P1	120	0	7	5	6	5
N4P2	120	30	16	12	14	10
N4P3	120	60	17	13	15	12
Mean			10	7	9	7
Effects			**F-probability**			
N			**	**	**	**
P			**	**	**	**
N * P			**	**	**	**

Expt. 1 Ejura farm major season, *Expt. 2* Agric College major season, *Expt. 3* Ejura farm minor, *Expt. 4* Agric College minor season, *NS* non-significant

*, ** Significant at 0.05 and 0.01, respectively

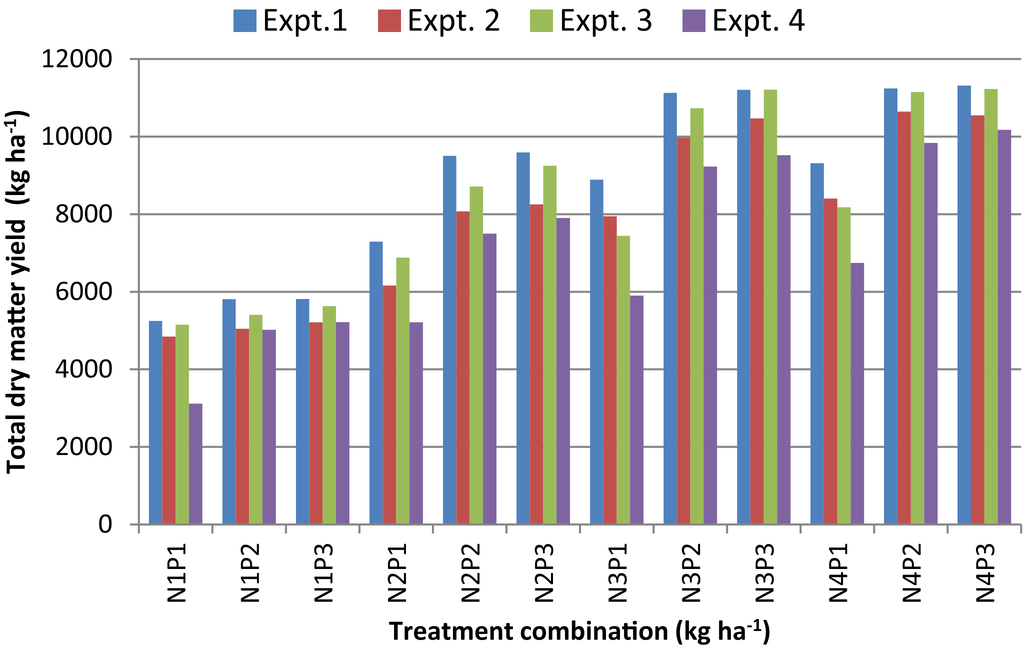

Fig. 9 Effect of nitrogen and phosphorus fertilizer on Obatanpa maize total biomass at Ejura during the major and minor season, 2008 (for legend, see Fig. 3)

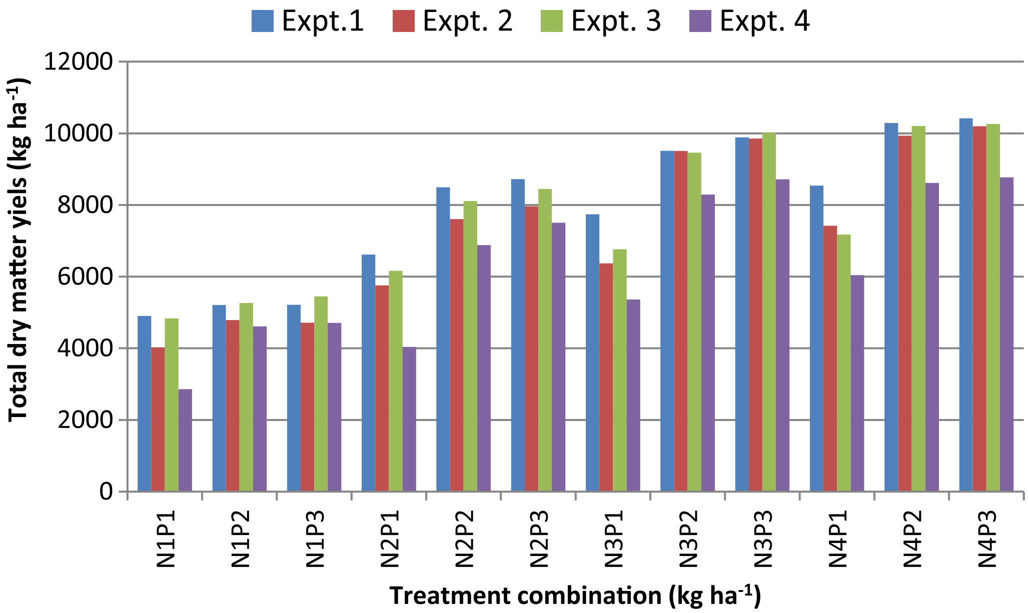

Fig. 10 Effect of nitrogen and phosphorus fertilizer on Dorke maize total biomass at Ejura during the major and minor season, 2008 (for legend, see Fig. 3)

of 11,320 kg ha^{-1} (N4P3) while in Dorke maize cultivar, TDM ranged from a minimum of 2858 kg ha^{-1}, in N1P1 (Expt. 4) to a maximum of 10,420 kg ha^{-1} in N4P3 (Expt. 1). In both varieties, total biomass was higher during the major season than the minor season. Similar findings have been reported by Kpongor (2007), Adiku et al. (2009), Arthur (2009) and Khaliq (2008). The differences in TDM between the two seasons are attributed to the amount and distribution of rainfall between and within the seasons. Pest attacks (stem borers) on some plants were observed during the minor season, which farmers said was the usual occurance during the minor seasons. Nitrogen uptake correlated well with total biomass production, which signifies the important role of N in the final biomass yield of the crop.

Harvest index

Table 6 presents the result of harvest index (HI) of Obatanpa during major and minor seasons 2008.

Grain filling is an important stage in the phenology of maize crops. Any stress due to insufficient moisture or nutrients at this time will adversely affect this process. The harvest index (HI), defined as the ratio of economic yield to biological yield is used to describe the accumulation and redistribution of assimilates to achieve final yield (Bange et al. 1998). In addition, harvest index (HI) shows the physiological efficiency of plants to convert the fraction of photo-assimilates to grain yield. According to Echarte and Andrade (2003), the vital determinants of crop yield are the harvest index value and its stability.

Results of ANOVA showed a statistically significant site difference ($p < 0.01$) on HI, with a higher mean HI of 0.37 at the Ejura farm (Expts. 1 and 3) compared to 0.36 at Agricultural College (Expt. 2 and 4). There was a significant ($p < 0.01$) seasonal difference on HI with 4.8 % increase in HI during the major season (Expt. 1) than during the minor season (Expt. 3). There was a higher HI obtained in Obatanpa (2.4 %) compared to Dorke, but this was only significant at Ejura farm site (Expt. 1 and 3). There was a significant influence of N ($p < 0.01$) on HI in all experiments for concentrations of N up to 80 kg N ha^{-1}. Similarly, interactive effect of N and P on HI was observed only in Expt. 1 ($p < 0.05$) and Expt. 4 ($p < 0.01$) in the Obatanpa variety.

Similar trends were observed in Dorke maize variety. Statistically, significant effects ($p < 0.01$) of N on HI in Dorke maize variety were observed in all experiments for all levels of N up to 80 kg N ha^{-1}. No interactive response of N and P on HI was however observed.

Generally, in this study, the treatments that promoted better growth of the maize crop had a positive influence on HI, presumably due to faster growth and partitioning of more carbohydrates into the grain. All treatments had higher HI compared to the control, reflecting poor plant growth in the control. The results suggest that an optimum N supply is essential for optimized partitioning of DM between grain and other parts of the maize plant. Similar results were reported by Fosu (1999) and Khaliq (2008). The HI of maize has been reported to be 0.5 for most tropical maize crops (Hay and Gilbert 2001).

Table 6 Effect of N and P fertilizer on harvest index of Obatanpa maize at Ejura during major and minor season 2008

Treatment combination	**Total biomass (kg ha^{-1})**					
	N (kg ha^{-1})	**P (kg ha^{-1})**	**Expt. 1**	**Expt. 2**	**Expt. 3**	**Expt. 4**
N1P1	0	0	0.31	0.25	0.25	0.30
N1P2	0	30	0.28	0.26	0.24	0.23
N1P3	0	60	0.29	0.27	0.24	0.24
N2P1	40	0	0.40	0.39	0.37	0.32
N2P2	40	30	0.38	0.37	0.37	0.36
N2P3	40	60	0.40	0.37	0.38	0.37
N3P1	80	0	0.42	0.41	0.44	0.44
N3P2	80	30	0.43	0.42	0.39	0.40
N3P3	80	60	0.43	0.43	0.40	0.40
N4P1	120	0	0.42	0.42	0.45	0.44
N4P2	120	30	0.44	0.43	0.40	0.39
N4P3	120	60	0.43	0.43	0.41	0.39
Mean			0.39	0.37	0.36	0.36
Effects			**F-probability**			
N			**	**	**	**
P			NS	NS	*	**
N * P			*	NS	NS	**

NS non-significant

*, ** Significant at 0.05 and 0.01, respectively

However, in all treatments, the HI values recorded were below the value (0.5) reported by Hay and Gilbert (2001). Low HI values can be attributable to late sowing, low plant population, diseases and unavailability of water at the critical growth stage of the crop (Ahmad et al. 2007).

Apparent nitrogen recovery (ANR)

The approach used does not take into account the effect of applied N on the transformation of native soil N, or the difference in soil N exploitation as determined by the increased size of the root system of the fertilized crops. As a result, the actual N recovery by the test crop may be over-estimated. Generally, ANR in grain was higher at the Ejura farm site than at Agricultural College, while the opposite is true for ANR in stover. The site difference on ANR was significant ($p < 0.01$) in both grain and stover with 11.7 % increase in ANR in the grain at the Ejura farm site (Expt. 1 and Expt. 3) and a 20.6 % reduction in the stover when compared to the Agricultural College site. There was no significant seasonal difference on ANR in grain. The ANOVA results revealed a significantly ($p < 0.01$) higher ANR in Obatanpa variety than in Dorke for grain. Averaged across sites, ANR of Obatanpa grain was 9.4 % higher than that of Dorke. Apparent N recovery generally decreased with increasing N rates but increased with increasing P rate. The ANR at 0 kg P ha^{-1} was significantly lower than for 30 and 60 kg P ha^{-1} for both varieties. For Obatanpa, an interactive effect ($p < 0.01$) of N and P was observed only in Expt. 4 for grain ANR.

The application of N and P fertilizer in Dorke increased ANR of aboveground biomass. In Expt. 1, ANR in grain ranged from 30.7 to 68.2 %. The application of 60 kg P ha^{-1} fertilizer increased ANR in grain by 31.5, 36.5 and 25.3 % for N concentrations of 40, 80 and 120 kg N ha^{-1}, respectively. In Expt. 2, the increase was 25.5 to 61.8 % while Expt. 3 and 4 showed similar values, with ANR in grain ranging from 27.3 to 73.1 and 23.5 to 70.1 %, respectively.

Excessive rain will increase N loss through leaching and denitrification and reduce N uptake. Low rainfall will restrict root growth and reduce N uptake. These effects will be exacerbated under climate change when there is excessive rain leading to flooding or low rainfall leading to drought.

Conclusion

Based on the results, the following conclusions are drawn: Inorganic fertilizer use in the study area was agronomically efficient, though generally more efficient at the Ejura farm site than at the Agricultural College site. Increasing N rates significantly increased grain and TDM production irrespective of application of P fertilizer. The application of inorganic P fertilizer increased the efficient utilization of inorganic N fertilizer by the plants in grain yield and total biomass production, hence, P nutrition of soils is critical for the efficient use of inorganic N fertilizer in the area.

Grain yield among various treatments was related to their photosynthetic activity and the soil conditions. Though plants were more responsive to N fertilizer applications, deficiency in soil P limited the efficient use of applied N by the plants. Owing to the spatial variability in soil nutrients in the area, site-specific recommendation of fertilizer application is suggested for efficient fertilizer use. Though the cultivars were different, they reacted similarly to N and P inorganic fertilizer application. The Obatanpa maize cultivar, however, was more responsive to inorganic fertilizer by producing higher grain yield than Dorke. Soil total Nitrogen in Haplic Lixisol within the sub-humid zone of Ghana ranges between 0.04 and 0.15 mg ka^{-1} while available P ranges between 3.5 and 18 mg ha^{-1}. The soil N and P of the study area falls within the range of soil nutrient in the zone, hence, the finding of this study can be applied onto a large-scale farmland.

Based on the findings of this study, it is recommended that in developing fertilizer recommendation for a cropping system, site specific nutrient stock should be considered. In order to improve the rate of fertilizer adoption, the government should subsidize the cost of fertilizer and widen the subsidy to different types of fertilizer in order to make it affordable for farmers to purchase to increase crop productivity.

Abbreviations

P: phosphorus; N: nitrogen; Expt. 1: Experiment 1; Expt. 2: Experiment 2; Expt. 3: Experiment 3; Expt. 4: Experiment 4; FAO: Food and Agriculture Organisation; RCBD: randomized complete block design; DM: dry matter; ANR: apparent nitrogen recovery; GLM: general linear model; ANOVA: analysis of variance; TDM: total dry matter; HI: harvest index; N1: 0 kg N ha^{-1}; N2: 40 kg N ha^{-1}; N3: 80 kg N ha^{-1}; N4: 120 kg N ha^{-1}; P1: 0 kg P ha^{-1}; P2: 30 kg P ha^{-1}; P3: 60 kg P ha^{-1}.

Authors' contributions

FMBY designed the study and collected, analyzed the data and drafted the manuscript, MM reviewed and contributed to the writing of manuscript. Both authors read and approved the final manuscript.

Author details

[1] Institute for Environment and Sanitation Studies (IESS), University of Ghana, Legon, P. O. Box 209, Accra, Ghana. [2] Center for Development Research (ZEF), University of Bonn, Walter-Flex Strasse 3, 53113 Bonn, Germany. [3] Department of Architecture, College of Architecture and Planning, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Acknowledgements

The authors greatly appreciate financial support from the German Federal Ministry for Education and Research (BMBF) to conduct this research.

Competing interests

All authors declare that they have no competing interests.

Received: 7 March 2016 Accepted: 20 August 2016

References

Adiku SGK, Jones JW, Kumaga FK, Tonyigah A (2009) Effects of crop rotation and fallow residue management on maize growth, yield and soil carbon in a savannah-forest transition zone of Ghana. J Agric Sci 147(313):322. doi:10.1017/S002185960900851X

Ahmad R, Hassan B, Jabran K (2007) Improving crop harvest index. Ramazan 18, 1428. Daw. Gr. Newspapers. http://www.DAWN.com

Akinnifesi FK, Makumba W, Sileshi G, Ajayi OC, Mweta D (2007) Synergistic effect of inorganic N and P fertilizers and organic inputs from *Gliricidia sepium* on productivity of intercropped maize in Southern Malawi. Plant Soil 294:203–217

Arthur A (2009) Effect of decompositing crop residues on soil property and crop productivity in the sub-deciduous forest zone of Ghana. Kwame Nkrumah University of Science and Technology, Kumasi (unpublihsed PhD thesis).

Balemi T, Negisho L (2012) Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. J Soil Sci Plant Nutr 12(3):547–562. doi:10.4067/S0718-95162012005000015

Bange MP, Hammer GL, Rickert KG (1998) Temperature and sowing date affect the linear increase of sunflower harvest index. Agron J 90:324–328. doi:10.2134/agronj1998.00021962009000030002x

Bationo A, Mokwunye U, Vlek PLG, Koala S, Shapiro BI (2003) Soil fertility management for sustainable land use in West Africa. In: Gichuru MP, Bationo A, Bekunda MA, Goma HC, Mafongonya PL, Mugendi DN, Murwira HM, Nandwa SM, Nyathi P, Swift MJ (eds) Soil fertility management in Africa: a regional perspective. Academy of Science Publishers, Ken

Bray RH, Kurtz LT (1945) Determination of total and organic and available forms of phosphorus in soils. J Soil Sci 59:39–45

Bremner JM, Mulvaney VA (1982) Steam distillation methods for ammonium nitrate and nitrite. Anal Chim Acta 32:485–495

da Xavier FAS, Almeida EF, Cardoso IM, de Mendonça ES (2011) Soil phosphorus distribution in sequentially extracted fractions in tropical agroecosystems in the Atlantic forest biome, southeastern Brazil. Nutr Cycl Agroecosyst 89:31–44. doi:10.1007/s10705-010-9373-5

Delve RJ, Probert ME, Cobo JG, Ricaurte J, Rivera M, Barrios E, Rao IM (2009) Simulating phosphorus resepose in annual crop using APSIM; model evaluation on contrasting soil types. Nutr Cycl Agroecosyst 84:293–306. doi:10.1007/s10705-008-9243-6

Echarte L, Andrade FH (2003) Harvest index of Argentina maize hybrids released between 1965 and 1993. F Crop Res 82:1–12. doi:10.1016/S0378-4290(02)00232-0

Fosu M (1999) The role of cover crops and their accumulated N in improving cereal production in Northern Ghana.Georg-August-University of Göttingen, Germany (unpublished PhD dissertation).

Fosu M, Kühne RF, Vlek PLG (2004) Improving maize yield in the Guinea savannah zone of Ghana with leguminous cover crops and PK fertilization. J Agron 3(2):115–121. doi:10.3923/ja.2004.115.121

Fosu-Mensah BY (2012) Modelling maize (*Zea mays* L.) productivity and impact of climate change on yield and nutrient utilization in sub-humid Ghana. Ecology and Development. PhD Dissertation, Series No. 87, pp 106–117

Gungula DT, Kling JG, Togun AO (2003) CERES-maize predictions of maize phenology under nitrogen-stressed conditions in Nigeria. Agron J 95:892–899. doi:10.2134/agronj2003.8920

Hay RKM, Gilbert RA (2001) Variability in the harvest index of tropical maize: evaluation of recent evidence from Mexico and Malawi. Ann Appl Biol 138:103–109. doi:10.1111/j.1744-7348.2001.tb00090.x

Khaliq T (2008) Modelling the impact of climate change on maize (*Zea mays* L) productivity in the Punjab. University of Agriculture, Faisalabad, Pakistan. (unpublished PhD dissertation).

Kpongor DS (2007) Spatially explicit modeling of sorghum (*Sorghum bicolor* (L.) Moench) production on complex terrain of a semi-arid region in Ghana using APSIM. Ecology and Development Series No 51. PhD Dissertation, pp 78–104

Landon JR (1996) Booker tropical soil manual. A handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman, Harlow

MacCarthy DS, Sommer R, Vlek PLG (2009) Modeling the impacts of contrasting nutrient and residue management practices on grain yield of sorghum (*Sorghum bicolor* (L.) Moench) in a semi-arid region of Ghana using APSIM. F Crop Res 113(2):105–115. doi: 10.1016/j.fcr.2009.04.006

McKeague JA (1978) Manual on soil sampling and methods of analysis, 2nd edn. Canadian Society of Soil Science, Ottawa, pp 189–204

McLean EO (1982) Soil pH and lime requirement. In: Page AL, Miller RH, Keeney DR (eds) Methods of Soil analysis, Part 2: Chemical and microbiological properties, 2nd edn. American Society of Agronomy and Soil Science Society of America, Madison, pp 199–224

Mustonen PJ, Oelbermann M, Kass DCL (2012) Using *Tithonia diversifolia* (Hemsl.) Gray, in a short fallow system to increase soil phosphorus availability on a Costa Rican Andosol. J Agric Sci 4:91–100. doi:10.5539/jas.v4n2p91

Nelson DW, Sommers LW (1982) Total carbon, organic carbon and organic matter. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2, Chemical and microbiological properties. 2nd edn. American Society of Agronomy and Soil Science Society of America, Madison, pp 301–312

Page AL, Miller RH, Keeney DR (1982) Nitrogen-inorganic forms. Methods of soil analysis. No. 9, part 2. American Society of Agronomy Inc. and Soil Science Society of America Inc., Madison, pp 643–698

Saha S, Saha B, Murmu S, Pati S, Roy PD (2014) Grain yield and phosphorus uptake by wheat as influenced by long-term phosphorus fertilization. African J Agric Res 6(9):607–612. doi:10.5897/AJAR2013.7525

Sharma A, Rawat US, Yadav BK (2011) Influence of phosphorus levels and phosphorus solubilizing fungi on yield and nutrient uptake by wheat under sub-humid region of Rajasthan, India. ISRN Agron 2012:9. doi:10.5402/2012/234656

Stewart JWB, Tiessen H (1987) Dynamics of soil organic phosphorus. Biogeochemistry 41:41–60

Walkley A, Black IA (1934) An examination of the Degtjaref method for determining soil organic matter, and a proposed modification of the chronic acid titration method. J Soil Sci 37:29–38. doi:10.1097/00010694-193401000-00003