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Effects of nitrogen, phosphorus and soil water content on growth and nutrient uptake of maize (*Zea mays* L.) grown on Fluvisols in Tigray, Northern Ethiopia

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Abstract

A greenhouse experiment was conducted in 2011 main season to determine the effects of different levels of N (0, 23, 46 and 69 kg N ha^{-1}), P (0, 10, 20, 30 and 40 kg P ha^{-1}) and soil water content (25, 50, 75, and 100% of field capacity) on growth and N and P uptakes of maize (*Katumani* variety) grown on Fluvisols in Mekelle, Ethiopia. A completely randomized design was used in a factorial arrangement with three replications. Interaction levels of 69 kg N ha^{-1}, 10 kg P ha^{-1}, and 100% of soil water content at field capacity (FC); 46 kg N ha^{-1}, 40 kg P ha^{-1} and 100% FC; 69 kg N ha^{-1}, 30 kg P ha^{-1} and100% FC and 23 kg N ha^{-1}, 40 kg P ha^{-1} and100% FC significantly ($P \leq 0.01$) increased plant height, total dry matter weight, N uptake and P uptake over the control treatment of the interactions, respectively. Amount of soil P remained in soil was highest at the interaction rate of 0 kg N ha^{-1}, 40 kg P ha^{-1} and 75 % FC. Soil moisture content and N were observed to increase use of P by maize at the nearly peak vegetative stage. Application of 46 kg N and 30 kg P ha^{-1} can be recommended for maize grown on Fluvisols at an early stage provided that soil water content is maintained at field capacity. This has to be supported by further study in the field especially at the latter stages of the crop.

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Introduction

Several centuries of human settlement in the northern Ethiopian highlands, associated with excessive deforestation, improper soil management, rugged topography and erratic rainfall conditions have resulted in extreme land degradation, which has currently reached a level difficult to undertake agriculture.

Water erosion and excessive plant nutrient exhaustion are the most critical problems, particularly in the densely populated and intensively cultivated highlands of Ethiopia where cereals are predominantly grown. The problems of land degradation have reached a critical level manifested by shallow soil depths, poor soil fertility and extremely low crop yields. Currently, the nation's number one problem is considered to be soil degradation, which can be noted from the country's low agricultural productivity. As a result, deficiencies of nitrogen (N) and phosphorus (P) are common in the highlands of Ethiopia (Betru, 1999). Tigray Region, especially the central and eastern part, is situated in the highlands of Ethiopia.

Chemical fertilizer studies in Ethiopia have mostly been aimed at determining the optimum rate of fertilizers for N and P. Blanket recommendation that was made for most areas of Ethiopia, including Tigray Region (23 kg N + 20 kg P ha^{-1}), was irrespective of crop, soil type and agro-climatic variation. However, such blanket recommendation was based on fertilizer rate trials in specific location, climate and soil type which has not contributed to crop production due to high variability of these factors. Despite the criticism of the limitations on the current fertilizer application rates, they are still widely practiced. On the other hand, in many parts of Ethiopia, the use of chemical fertilizers on food crops is limited (Betru, 1999). This also holds true for the Tigray Region.

Nitrogen and P fertilizer trials previously conducted by the Ethiopian Institute of Agricultural Research and by other national and regional agricultural research institutes were only in some pocket areas in Tigray. Application of P and N fertilizers by farmers for most crops, including maize has become a necessity in most parts of Tigray Region in particular and in the Ethiopian highlands in general.

Small scale (1:2000000) unpublished soil map from Tigray National Regional State Finanance and Economic Development Bureau (TNRSFEDB), (2003) indicated that Cambisols, Vertisols, Nitosols and Fluvisols are among the major soil types available, covering most of the areas in Tigray. Fluvisols are among the major soil types in Agulae-Womberta, Tigray, from which the soil samples used for this study were collected. Fluvisols are young soils developed in recent alluvial deposits of river plains, deltas, former lakes and coastal areas having highly variable soil properties. The Fluvisols are important because they are usually found in places where floods of rivers and streams are available. In Agulae-Womberta too, Fluvisols occurring along the courses of river are irrigated. However, these soils are agriculturally underutilized because of constraints related to inefficient water and nutrient management practices by traditional farming. Hunting Technical Service Limited (HTSL), (1976) had reported low N and P on the Fluvisols of the Agulae-Womberta area. They are in a semiarid region and are characterized by sandy loam texture with high hydraulic conductivity, low total N and available P and organic matter having alkaline soil pH. The soils are mainly cultivated for vegetables and maize. Farmers in the area use irrigation water to produce crops from a nearby river, which is sometimes insufficient. However, they irrigate their fields traditionally without taking exact amount of soil moisture content for each crop into account. They also use N and P fertilizers using the blanket recommendation. This is due to the absence of specific research-based water and fertilizer recommendations.

There is a close relationship between soil moisture content and nutrient availability to plants (Ibrahim and Kandil , 2007; Hussaini *et al.*, 2001). It is generally believed that the greatest benefit from fertilizer application can be derived under irrigated conditions, where water supply is least likely to limit nutrient uptake. Hussaini (2008) and Quaye et al. (2009) found that where no N fertilizer was applied there was no significant difference between heights of maize plants grown on different levels of soil water content as percentages of water content at field capacity. However, when higher N was applied, there was a significant difference in plant height showing the interaction effect of N and soil water content. Nutrient amount and availability also varies for different crop types or varieties. Maize has high production potential especially under irrigated conditions when compared to any other cereal (Kumar, *et al.* 2007).

crop. The productivity of maize cultivars largely depends on its nutrient requirement and management particularly that of N and P (Kumar et al., 2007; Karlen *et al.*, 1987). Jones (1985) and Chirnogeanu et al. (1997) similarly reported by stating that corn plant requires N and P soon after germination to initiate the growth of stems, leaves and ear structures.

The low N and P content of the soils leading to existing inevitable fertilize use, inefficient traditional water use by farmers as well as absence of previous specific studies to solve these problems calls for initiating nutrient and water related studies on the Fluvisols in the Agulae-Womberta valley. Hence, this study aims at initially examining the effects of different levels of N and P rates as well as water treatments calculated on the basis of soil moisture content at field capacity on growth and N and P uptakes of maize under a greenhouse condition.

Materials and methods

Description of the study area

The study was conducted under a greenhouse condition from 20 July to 5 September, 2011 in Mekelle University, northern Ethiopia (latitude 13°28´ N; longitude 39° 29´ E and altitude of 2215 m above sea level) which is semi-arid in agro-ecology. Topography of the Tigray Region including Agulae-Womberta site is mainly the extension of the central highland which is comprised of highlands. Agulae-Womberta has flat terrain with slopes seldom exceeding one per cent. It is intensively cultivated for cereals and pulse crops and is irrigated, with fresh alluvium along river bank. The soils are highly suitable for dry land or irrigated arable farming (HTSL, 1976).

The rainy season around Mekelle city starts in late June and ends in early September and is erratic in its distribution. The mean annual rainfall is 607 mm, the mean annual temperature ranges from minimum of 10.7 to maximum of 24.3 °C, while the humidity ranges from 48% during dry season to 60% during the rainy season. Fluvisol is one of the major soil types in the study area and is derived from alluvium parent material. It is classified as Eutric Fluvisols (HTSL, 1976). Farmers in Agulae-Womberta produce cereals mainly maize, wheat and teff during rainy season and vegetables as well as maize during off season by irrigation. The farmers of the area use supplementary irrigation when rainfall stops at the end of the growing season. Maize is produced twice per year. Yield of maize varies during the two seasons and the highest yield can reach 4 t ha^{-1} when farmers use fertilizer, other high yielding varieties and irrigation. However, according to the farmers in the study area, yield for *Katumani* is relatively low but they prefer this variety for its early maturity.

Soil sampling and sample preparation

Prior to the establishment of the experiment, plow layer (0-15 cm) soil samples were collected for both physico-chemical analyses and for pot experiment.

The samples were collected from 2 km east of Agulae village which is about 25 km north east of Mekelle city, Tigray. One composite sample was prepared from 10 holes at 100 m distances for the laboratory analyses of soil properties, using auger. The sample for the pot experiment was collected from 10 spots at 100 m distances using spade and shovel into sacks and then thoroughly mixed. Similarly, undisturbed soil samples were collected using core sampler for soil bulk density and water retention at field capacity (FC) determinations. The samples were transported to Mekelle to be used for pot experiment as well as for the soil laboratory analysis.

Greenhouse experiment

A factorial experiment in a completely randomized design in three replications was laid down in a greenhouse using plastic containers. Three factors consisting of four rates of N (0, 23, 46 and 69 kg N ha^{-1}), five rates of P (0, 10, 20, 30 and 40 kg P ha^{-1}) and four levels of water content (25, 50, 75 and 100 % of FC of the soil) were applied to pots. The pots were arranged on cemented platform. The soil sample for the pot experiment was air dried, crushed, weighed and filled into the plastic pots. Two hundred forty plastic containers with 21 cm diameter and 18 cm height were used for the experiment. Each plastic container was filled with 4 kg of the soil to 12 cm of its height. Nitrogen was applied at once as urea while P was applied as triple super phosphate (TSP). The amounts of urea and TSP were calculated for each level for the 4 kg of soil by taking the bulk density of the soil into account. The amounts of fertilizers for each pot were then weighed using sensitive balance and mixed with the soil before sowing the seeds.

A maize variety*, Katumani,* which has been widely used by farmers around the sampled area, was used for the study as a test crop. Three seeds were sown in each pot. Two seedlings out of the three were thinned after seven days from sowing date. Separate plastic pots were treated by taking the four water treatments as well as the N and P fertilizer applications to measure the weight of the plant to be deducted by calculating the daily increase of fresh total plant weight. The plants were harvested destructively at 5 day intervals, starting from 10 days after sowing (DAS), and weighed and averaged for every day. The weight of the plant for the next 5 days was considered by adding one day's fresh weight daily until the second harvesting, after 5 more days, and this was repeated until harvesting maize from the experimental pots. The weight of the plant was deducted to know the weight of water lost through evaporation. The experimental pots were daily weighed and the differences in the weights of the pots were ascribed to water lost by evapotranspiration. The daily lost water was replenished by adding an equal volume of water to that lost from each pot to the pots until the plant was harvested. Plant height was measured at harvest (when many of the plants were at V_{10}, collar of 10^{th} leaf visible, vegetative growth stage) which was carried out at 45 DAS. The shoots and roots were separated from each other and the samples were taken to laboratory. Soil samples were collected from each pot immediately after harvesting for analysis of P remained in the soil.

Laboratory methods

Particle size distribution was determined by the hydrometer method (Day, 1965). Once the sand, silt, and clay separates were calculated in percent, the soil was assigned to a textural class based on the soil textural triangle using International Soil Science Society (ISSS) system (Rowell, 1994). Dry bulk density was determined by the core method (Hesse, 1971). Soil moisture contents were measured using the method outlined by Black (1965). Soil water retention at FC was determined in laboratory by using a pressure plate to apply a suction of 1/3 bar to a saturated soil sample. When no longer water was leaving the soil sample, the soil water content in the sample was determined gravimetrically and equated to field capacity. Volumetric moisture retention at FC was then calculated by multiplying the gravimetric soil moisture content by the bulk density. The different FC water treatments were calculated on volume basis. The disturbed composite soil sample collected for the laboratory analysis was air dried, crushed using pestle and mortar and passed through a 2 mm diameter sieve for analysis of most of the soil chemical properties. A portion of the disturbed soil sample was taken and sieved using 0.5 mm diameter sieve for the determination of organic carbon and total N. Soil pH in water was determined by the glass electrode pH meter (Peech, 1965) at 1:2.5 soil to water ratios. The electrical conductivity (EC) of the soil was measured according to the method described by Peech (1965). The cation exchange capacity (CEC) was determined by the method described by Chapman (1965). Percent base saturation (PBS) was calculated from exchangeable potassium ion (K), calcium ion (Ca), magnesium ion (Mg), sodium ion (Na) and CEC. Potassium and Na were determined using flame photometer as described by Rowell (1994), while Ca and Mg were determined by atomic absorption spectrophotometer method (Hesse, 1971). Calcium carbonate ($CaCO_3$) was determined by titration according to FAO (1974). The total N contents in soils were determined using the Kjeldahl procedure by oxidizing the organic matter with sulfuric acid and converting the N into ammonium ion (NH_4) as ammonium sulfate (Sahlemedhin and Taye, 2000). Soil available P was analyzed using Olsen method (Olsen et al., 1954) modified by Watanabe and Olsen (1965). To determine organic carbon, the Walkley and Black (1934) method was employed. Finally, the organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724. Shoot and root samples were separately dried in oven at 65 ^{o}C for about 72 hours during which constant weight was obtained (Jones and Case, 1990). They were weighed with sensitive balance and then fine ground for subsequent total N and P determination. The plant samples were dried, wet digested and analyzed for total N, using the Kjeldahl method. Dried plant samples were dry ashed using furnace at 300 ^{o}C for five hours and analyzed for P content as for the soil P.

Data analysis

The effects of the three factor treatment combinations on plant height, dry matter weight, N and P uptakes and P remained in soil were determined using analysis of variance appropriate for completely randomized design. Analyses of variance on data of these variables were performed using MSTATC software (Michigan State University, 1991). Duncan's multiple range tests was used to separate means as the number of treatments are many, above six (Gomez and Gomez, 1984).

Results and discussion

Soil properties

The results of laboratory analyses of physical and chemical properties of Agulae-Womberta Fluvisols are shown in Table 1. The textural class of the soil under investigation is sandy loam based on the soil textural triangle of International Soil Science Society (ISSS) system (Rowell, 1994). According to the rating by Hazelton and Murphy (2007), sand was very high but silt and clay particles were low. Bulk density was moderate according to Harte (1974). The depth of water at 100% FC was calculated to be 62.93 mm water m^{-1} soil depth. The available water content calculated was low that is 50.98 mm water m^{-1} soil depth which is within the range for sandy texture soil (25-100 mm water m^{-1} soil depth) according to FAO (1985). Based on CaCO3 rating suggested by Nachtergaele et al. (2009), the soil of the study area was moderately calcareous in nature. The soil was low in organic carbon as per rating suggested by Charman and Roper (2007). The data further revealed that the soil was moderately alkaline according to Bruce and Rayment (1982). On the basis of EC limit proposed by Shaw (1999), the soil under investigation falls in the category of non saline soils. The soil has low CEC value, on the basis of CEC rating by Metson (1961), and this might be due to its coarse texture, low organic matter and presence of $CaCO_3$. The exchangeable K and Ca were high but exchangeable Na and Mg were moderate as per the rating by Metson (1961). The PBS calculated from these cations was very high according to rating by Metson (1961). Based on the rating set by Landon (1991), the available phosphorus in the plow layer of the soil was low. As per the rating set by Bruce and Rayment (1982), soil total N was low (Table 1).

Table 1. Physical and chemical properties of Fluvisols in Agulae-Womberta, northern Ethiopia

Soil properties	Value
Sand (%)	67
Silt (%)	19
Clay (%)	14
Textural class	Sandy loam
Bulk density (g cm^{-3})	1.4
Volumetric soil moisture content at field capacity (%)	9.97
pH 1:2.5 (H_2O)	8.1
EC (dS m^{-1}) in 1:2.5 soil to water ratio	0.11
$CaCO_3$ (%)	7.0
Soil organic matter (%)	1.41
Total N (%)	0.11
Available P (mg kg^{-1})	5.08
Exchangeable Ca (cmol (+)kg^{-1})	6.86
Exchangeable Mg (cmol (+)kg^{-1})	1.2
Exchangeable Na (cmol (+)kg^{-1})	0.31
Exchangeable K (cmol (+)kg^{-1})	0.84
Cation exchange capacity (cmol (+)kg^{-1})	9.4
Percent base saturation (%)	97.87

Effects of N, P and soil water content on maize growth

The results of effects of N, P and soil water content on the different plant and soil parameters and the discussion are given under different topics and in different tables below.

Plant height

The interaction effects of N with P and with soil water content resulted in significantly ($P \leq 0.01$) higher plant height at the rates of 69 kg N ha^{-1}, 10 kg P ha^{-1} and 100% FC moisture content causing 57.2% (38.33 cm) increment followed by 69 kg N ha^{-1}, 20 kg P ha^{-1}, 100% FC soil water content resulting in 57.1% (38.16 cm) increment over the 0 kg N ha^{-1},0 kg P ha^{-1}, and soil water content at 25% FC treatment. The difference in height due to P was highest between 0 kg P ha^{-1} and 30 kg P ha^{-1} at 69 kg N ha^{-1}, and soil water content of 100% FC. It was observed that the effect of soil water content in the interaction with N and P on maize height was higher as compared to the effects of N and P (Table 2). Similarly, Ibrahim and Kandil (2007) reported that irrigation, N and P rate interactions positively affected plant height, showing decreased increment caused due to fertilizers application with the longer irrigation intervals in Egypt. Stichler and Farland (2011) also reported the primary limiting factor for crop production to be the availability of water and as water evaporates from plant leaves, the roots replace the water with soil moisture. They concluded that as the roots absorb water from the soil, they also absorb nutrients that are dissolved in the water. The height of plant is an important growth character directly linked with the productive potential of plants in terms of grains. An optimum plant height is claimed to be positively correlated with productivity of plant (Saeed *et al.*, 2001). According to Haseeb-urehman *et al.* (2010) plant height is an important yield component, as more green areas imply more photosynthetic activity and more will be shared with grain yield. Nye and Tinker (1977) reported that lower water availability causes a reduction in P availability and, therefore, in its absorption.

Table 2. Interaction effect of N, P and soil water content on mean height (cm) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	28.67D	30.00CD	39.50w-zA	36.83yzAB	36.00yzABC	34.20
	50	39.67w-zA	44.50q-x	44.830-w	38.67w-zAB	38.20xyzAB	41.17
	75	42.33t-y	40.83v-z	53.50c-n	51.00j-q	58.17b-g	49.17
	100	51.17j-p	52.67d-n	57.83b-i	54.00b-m	49.83k-s	53.10
	Mean	40.46	42	48.92	45.13	45.55	44.41
23	25	33.33A-D	39.67w-zA	41.33u-z	44.67p-x	47.00n-v	41.20
	50	39.33w-zA	44.00s-x	47.80m-t	44.17r-x	51.50h-n	45.36
	75	51.83f-n	55.50b-k	53.50c-n	53.10c-n	48.33l-t	52.45
	100	48.83k-s	54.67b-l	58.33b-f	58.67b-e	58.00b-h	55.70
	Mean	43.33	48.46	50.24	50.15	51.21	48.68
46	25	33.50 A-D	35.83yzABC	36.33yzABC	38.67w-zAB	34.83zA-D	35.83
	50	37.33yzAB	46.90n-v	51.67g-n	51.27i-p	48.33l-t	47.10
	75	49.67k-s	52.17e-n	56.83b-j	59.17bcd	56.67b-j	54.90
	100	49.33k-s	58.00b-h	59.67bc	59.50bc	60.17b	57.33
	Mean	42.46	48.23	51.13	52.15	50.00	48.79
69	25	32.50 BCD	33.67A-D	35.83yzABC	39.33w-zA	36.37yzABC	35.54
	50	36.17yzABC	39.83w-zA	49.83k-s	51.50h-n	47.50m-u	44.97
	75	58.17b-g	59.50bc	51.33i-o	50.67j-r	51.00j-q	54.13
	100	57.00b-j	67.00a	66.83a	53.83b-m	51.83f-n	59.30
	Mean	45.96	50.00	50.96	48.83	46.68	48.49
Mean		43.0525	47.17	50.31	49.07	48.36	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01.
Coefficient of variation (CV) = 5.24%.

Dry matter weight

Significantly (P ≤ 0.01) higher interaction effects of N, P and soil water content were observed on shoot dry weight when combined levels of 69 kg N ha^{-1}, 10, 20 and 30 kg P ha^{-1} and soil water at 100% FC were applied over the control treatment (0 kg N ha^{-1},0 kg P ha^{-1}, and soil water content at 25% FC). The highest shoot dry matter weight figure was 8.743 g plant^{-1} (460.5% increment over the control) even though the difference was not significant compared with the mentioned two combined rates which showed higher shoot dry matter weight (Table3). Highest increments in shoot dry matter weight were observed between soil water content at 25% FC and100% FC at 69 kg N ha^{-1} treatment at all applied P levels. Shoot dry matter response to applied P was different in the presence of different rates of N and soil water content used in the experiment. At the highest N, maize shoot dry matter weight was highest at the lower P rate (10 kg P ha^{-1}) but at the lower rates of N, the highest response to P was at higher P levels (20-40 kg P ha^{-1}) when soil water content was at 100% FC.

The interaction effect of 23 kg N ha^{-1}, 40 kg P ha^{-1} and soil water content at 100% FC caused significant (P ≤ 0.01) increment in root dry matter weight of the maize plant. The highest root dry matter weight obtained by applying this interaction treatment was 5.560 g plant^{-1} (with 368.4% increment over the control treatment). The interaction effect on root dry matter weight showed an increasing trend at all levels of applied N treatments with increasing levels of soil water content and P treatments. Highest root dry matter weight was observed at the highest level of P (40 kg

P ha^{-1}) and at relatively lower level of N (23 kg N ha^{-1}). This study indicated that maize root used a smaller amount of N but a higher level of P in the presence of water (Table 4). Mollier and Pellerin (1999) similarly observed that root growth was strongly reduced after P starvation and concluded that emergence of new axial roots and elongation of first-order laterals was drastically reduced.

Table 3. Interaction effect of N, P and soil water content on mean shoot dry matter weight (g plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (% FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	1.560I	1.650I	2.120GHI	3.650u-zA	2.483D-H	2.2926
	50	2.913A-F`	2.950A-F	2.967zA-F	3.237w-zA-D	2.837B-G	2.9822
	75	3.307w-zABC	3.947s-x	4.837opq	4.030r-w	4.543p-t	4.1328
	100	4.900n-q	5.270 l-p	4.713p-s	5.773i-m	4.337q-u	4.9986
	Mean	3.170	3.456	3.66	4.173	3.550	3.602
23	25	1.803HI	3.333w-zABC	3.330w-zABC	5.237m-p	3.297w-zABC	3.4000
	50	3.250w-zA-D	3.193xyzA-D	5.000m-q	3.553v-zAB	3.950s-x	3.7892
	75	4.580p-t	4.893n-q	4.947n-q	5.610k-o	6.437g-j	5.2934
	100	5.280 l-p	6.500f-i	6.903efg	5.790i-m	6.423g-j	6.1792
	Mean	3.728	4.480	5.044	5.048	5.027	4.665
46	25	1.923HI	2.340 E-I	2.557 C-H	2.477 D-H	2.007HI	2.2608
	50	3.510w-zAB	3.630u-zAB	3.837t-y	4.730pqr	3.567u-zAB	3.8548
	75	5.327l-p	5.657k-n	5.080m-q	6 .030h-l	6.250g-k	4.4628
	100	5.597k-o	7.613cde	6.677fgh	7.403cde	7.780bcd	7.0140
	Mean	4.089	4.810	4.538	5.160	4.901	4.398
69	25	1.800HI	1.800HI	1.853HI	2.293E-I	2.210F-I	1.9912
	50	3.040yzA-E	3.540v-zAB	3.763u-z	4.763pqr	4.310q-v	3.8832
	75	4.533p-t	6.360g-k	5.683j-n	5.240m-p	5.223m-p	5.4078
	100	7.553cde	8.743a	8.400ab	8.103abc	7.173def	7.9944
	Mean	4.232	5.111	4.9248	5.100	4.729	4.819
Mean		3.80475	4.464125	4.541688	4.869938	4.551688	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 6.83%.

The effect of the three factors indicated significantly (P ≤ 0.01) higher results at the interaction rates of 46 kg N ha^{-1}, 40 kg P ha^{-1}, and at 100% FC soil water content; 23 kg N ha^{-1}, 40 kg P ha^{-1}, and at 100% FC soil water content; 46 kg N ha^{-1}, 20 kg P ha^{-1}, and at 100% FC soil water content and 69 kg N ha^{-1}, 10 kg P ha^{-1}, and at 100% FC soil water content compared to the control treatment and many other treatments (Table 5). Interaction rate of 46 kg N ha^{-1}, 40 kg P ha^{-1}, and 100% FC soil water content showed highest figure among the four treatments that showed higher results, causing 355% (9.75g plant^{-1}) increment of total dry matter weight (shoot plus root dry matter weights) over the control treatment level (Table 5). Karlen *et al.* (1987) and Jones (1985) in agreement with this finding reported the positive effects of better water management and increased nutrient application on dry matter accumulated in maize (Quaye *et al.*, 2009) showing peaks during vegetative growth stage and during grain-fill stages.

Nitrogen and P uptake by maize and p remained in soil

Nitrogen uptake

Nitrogen uptake pattern by maize is presented in Table 3. Significant (P ≤ 0.01) differences were observed because of the three factor interaction effects among applied N, applied P and soil water content on shoot N uptake. Interaction rates of 69 kg N ha^{-1}, 0 kg P ha^{-1}, and at 100% FC soil water content; 69 kg N ha^{-1}, 30 kg P ha^{-1}, and at 100% FC soil water content; 69 kg N ha^{-1}, 20 kg P ha^{-1}, and at 100% FC soil water content and 69 kg N ha^{-1}, 10 kg P ha^{-1}, and at 100% FC soil water content gave significantly ($P \leq 0.01$) higher shoot N uptake compared to the control treatment and most other treatments. For instance, interaction rate of 69 kg N ha^{-1}, 0 kg P ha^{-1}, and at 100% FC soil water content resulted in highest shoot N uptake (156.40 mg plant-1) causing 138.42 mg plant^{-1} increment over the control. Higher and lower N uptakes were observed at the higher and lower levels of applied N, respectively (Table 6). Similar results have been reported by different workers. Chirnogeanu *et al.* (1997) also observed that high level of soil N and P significantly influenced the nutrient uptake and translocation in leaves and caused N content in maize plants to increase at high levels of N and P when compared to low levels under irrigated condition in Romania. Hussaini *et al.*(2008) also found similar results in Nigeria. According to Vlek and Vielhauer (1994), the main stress in relation to N management is probably the uncertainty of rainfall where irrigation is not available. Where rainfall is excessive, N is subject to leaching or denitrification losses, while with drought it has a tendency to remain in the soil, unutilized by the crop.

Table 4. Interaction effect of N, P and soil water content on mean root dry matter weight (g plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	1.187E	1.287DE	1.390 C-E	1.717x-zA-E	1.553B-E	1.427
	50	1.590zA-E	1.873u-zA-D	2.450o-v	2.760j-s	2.487n-u	2.232
	75	2.330q-y	2.517m-u	2.820i-s	2.776j-s	3.270e-k	2.731
	100	2.560l-t	2.747j-s	3.060g-p	2.867i-r	3.470d-i	2.941
	Mean	1.917	2.106	2.430	2.515	2.695	2.338
23	25	1.313 DE	1.443CDE	1.440CDE	1.613zA-E	1.490B-E	1.171
	50	2.350-y	2.383p-x	2.530l-u	1.500B-E	2.153s-zAB	2.183
	75	2.753j-s	3.110f-o	2.950h-q	3.190f-m	2.737j-s	2.948
	100	2.240r-zA	2.633k-t	3.620d-g	3.347d-j	5.560a	3.480
	Mean	2.164	2.032	2.635	2.413	2.985	2.446
46	25	1.360CDE	1.427CDE	1.450CDE	1.573A-E	1.607zA-E	1.483
	50	1.533 DE	2.250r-z	1.683yzA-E	1.467CDE	2.670k-t	1.921
	75	2.013 t-zB-E	2.707j-s	2.730j-s	3.903 cde	2.230r-zA	2.717
	100	3.940cd	3.967cd	4.727b	3.197f-l	4.480bc	4.062
	Mean	2.2115	2.588	2.648	2.535	2.747	2.546
69	25	1.763w-zA-E	2.280q-y	2.140s-zAB	1.783v-zA-E	1.787v-zA-E	1.951
	50	2.150s-zAB	2.417p-w	2.327q-y	1.703yzA-E	2.553l-t	2.230
	75	2.953h-q	2.520l-u	3.247f-k	3.600d-h	3.050g-p	3.074
	100	3.357d-j	3.160f-n	2.880i-r	3.587d-h	3.737def	3.342
	Mean	2.556	2.594	2.649	2.668	2.782	2.650
Mean		2.212	2.330	2.590	2.533	2.802	

*Three factor interaction means followed by the same letter (s) are not significantly different at $P > 0.01$.
Coefficient of variation (CV) = 10.05%.

The interaction effects of the three factors resulted in significantly ($P \leq 0.01$) higher root N uptake at the levels of 46 kg N ha^{-1}, 20 kg P ha^{-1}, and at 100% FC soil water content followed by 46 kg N ha^{-1}, 40 kg P ha^{-1}, and 100% FC soil water content then after by some other treatments (Table 7) than the control treatment. Root N uptake at 46 kg N ha^{-1}, 20 kg P ha^{-1}, and 100% FC soil water content interaction was 51.02 mg plant^{-1}causing 388.2% increment compared to the control treatment (Table 7).

According to Hussaini *et al.* (2001) a certain degree of synergy between N and P has been reported for some field crops. A crop receiving balanced nutrition is able to explore a larger volume of soil in order to access water and nutrients. Plants facing moisture stress can also suffer from nutrient stress owing to the very close association between water and nutrient availability (FAO, 2006).

Table 5. Interaction effect of N, P and oil soil water content on mean total dry matter weight (g plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	2.747 F	2.937FE	3.510C-F	5.367u-y	4.037 BCD	3.7196
	50	4.503yzABC	4.803x-zAB	5.417u-y	5.997s-w	5.323u-y	5.2086
	75	5.637t-x	6.463rst	7.657l-q	6.747qrs	7.813k-p	6.8634
	100	7.460m-q	8.017i-o	7.773l-p	8.640g-l	7.807k-p	7.9394
	Mean	5.087	5.555	6.089	6.688	6.245	5.932
23	25	3.117DEF	4.777x-zAB	4.770x-zAB	6.850p-s	4.787x-zAB	4.8618
	50	5.600t-x	5.577t-x	7.530m-q	5.053w-z	6.103s-v	5.9726
	75	7.333o-r	8.003i-o	7.897j-o	8.800g-k	9.173fgh	8.2412
	100	7.520m-q	9.133fgh	10.530de	9.137fgh	11.980ab	9.6600
	Mean	5.893	6.873	7.684	7.460	8.011	7.184
46	25	3.767DEF	3.767CDE	4.007BCD	4.050A-D	3.613C-F	3.8408
	50	5.043w-zA	5.880s-w	5.520t-x	6.197s-v	6.237stu	5.7754
	75	7.340n-r	8.363h-n	7.810k-p	9.933ef	8.480h-m	8.3852
	100	9.537fg	11.580abc	11.400a-d	10.600 de	12.260a	11.075
	Mean	6.422	7.398	7.184	7.695	7.648	7.269
69	25	3.563C-F	4.080zA-D	3.993BCD	4.077zA-D	3.997 BCD	3.9420
	50	5.190v-y	5.957s-w	6.090s-v	6.467 r-t	6.863p-s	6.1134
	75	7.487m-q	8.880g-j	8.930ghi	8.840g-j	8.273h-o	8.4820
	100	10.91cd	11.90ab	11.280bcd	11.690abc	10.910cd	11.3380
	Mean	6.788	7.704	7.573	7.769	7.511	7.469
Mean		6.048	6.883	7.133	7.403	7.354	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01.
Coefficient of variation (CV) = 5.62%.

The interaction effect of the three factors indicated significantly (P ≤ 0.01) highest total plant N uptake at the interaction rate of 69 kg N ha^{-1}, 30 kg P ha^{-1}, and at 100% FC soil water content (192.10 mg plant^{-1}) causing 575.7% increment over its control. The interaction effects of 69 kg N ha^{-1}, 0 kg P ha^{-1}, and at 100% FC soil water content followed by some other treatments also caused significantly higher total plant N uptake compared to the control treatment (Table 8). This response of total N to the interaction treatments of N and P with soil water content over the control treatment agrees to the report by FAO (2006) stating that optimal nutrients without access to adequate water results in poor utilization of the nutrients. The report concludes that as nutrients need to move only a short distance, adequate soil moisture favors the mass flow of nutrients, especially N.

Phosphorus uptake

Interaction effects of 69 kg N ha^{-1}, 30 kg P ha^{-1} and 100% FC water content followed by some other three factor interaction treatment effects showed significant (P ≤ 0.01) results in shoot P uptake of maize. Nitrogen, P and soil water content treatment interaction showed the highest shoot P uptake at 69 kg N ha^{-1}, 30 kg P ha^{-1} and at 100% FC soil water content, causing 672% increment over the control treatment level (Table 9). Since nutrient uptake is closely linked to soil water status, it is expected that a decline of available soil moisture decreases the diffusion rate of nutrients from soil matrix to roots

(Ibrahim and Kandil, 2007) and maize cannot readily take up soil P in large amounts needed for optimal growth (FAO, 2006).

Table 6. Interaction effect of N, P and soil water content on mean shoot N uptake (mg plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	17.98G	41.18x-zA-G	23.49FG	43.68w-zA-G	37.33yzA-G	32.732
	50	33.88B-G	33.29C-G	42.59w-zA-G	37.39yzA-G	36..63zA-G	29.430
	75	56.29p-zA-E	41.78w-zA-G	83.74g-o	40.28yzA-G	41.95w-zA-G	52.808
	100	48.46s-zA-F	49.53s-zA-F	46.78u-zA-F	53.65r-zA-E	44.44v-zA-F	48.504
	Mean	39.153	41.445	49.065	43.750	30.930	40.869
23	25	31.01D-G	47.37t-zA-F	73.15j-t	103.9c-g	63.01lm-z	63.688
	50	62.35m-zA	61.18n-zA	88.15f-m	59.200-zABC	60.10m-zAB	66.196
	75	55.64q-zA-E	68.13j-w	70.32j-v	64.12k-y	84.23g-o	68.488
	100	73.67l-s	63.38m-y	72.20j-u	85.92f-n	63.02m-z	71.638
	Mean	55.668	60.015	75.955	78.285	67.590	67.503
46	25	49.04s-zA-F	53.11r-zA-E	67.76 k-w	51.64r-zA-E	46.30u-zA-F	53.570
	50	93.09d-k	79.70g-q	81.95g-p	94.22d-j	42.97w-zA-G	78.386
	75	82.10g-p	100.10c-i	101.00c-h	86.26f-n	85.79g-n	91.050
	100	93.02d-k	94..08d-j	101.00c-h	90.12e-l	90.83e-k	74.994
	Mean	79.313	58.228	87.928	80.560	66.473	74.500
69	25	42.28w-zA-G	44.50v-zA-F	30.37EFG	56.83p-zA-D	36.33A-G	42.062
	50	80.87g-q	76.62h-r	81.15g-q	111.80c-f	113.80 cde	92.848
	75	74.33i-s	151.40a	105.10c-g	85.65g-n	117.20bcd	106.736
	100	156.40a	137.30ab	153.90a	151.30a	124.30bc	144.640
	Mean	88.470	102.455	92.630	101.395	97.908	96.573
Mean		65.651	65.536	76.3945	75.998	65.725	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 13.63%.

Table 7. Interaction effect of N, P and soil water content on mean root N uptake (mg plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	10.45zA	12.29v-zA	10.19A	13.89u-zA	13.87u-zA	12.138
	50	11.54xyzA	17.97n-zA	27.70f-v	21.59k-zA	31.92c-q	22.144
	75	21.80j-zA	21.26k-zA	33.33c-n	20.77k-zA	28.53d-u	25.138
	100	27.65f-v	17.98 n-zA	27.12f-w	32.66c-p	37.10a-j	28.502
	Mean	17.860	17.375	24.585	22.228	27.855	21.980
23	25	14.75s-zA	13.36u-zA	17.650-zA	14.38t-zA	12.16w-zA	14.460
	50	28.31e-u	26.82f-x	26.58f-y	18.61m-zA	22.36i-zA	19.220
	75	26.27f-y	33.25c-n	37.16a-j	30.90c-r	30.78c-r	31.672
	100	25.06g-zA	19.92k-zA	34.38c-l	33.93c-m	43.35a-e	31.328
	Mean	23.598	23.338	22.298	24.455	27.163	24.170
46	25	11.30yzA	17.26p-zA	20.31k-zA	19.96k-zA	19.07l-zA	17.580
	50	15.75r-zA	25.72f-z	19.59l-zA	18.18n-zA	23.22h-zA	20.492
	75	19.36l-zA	30.66c-r	29.56d-t	38.77a-g	21.24k-zA	27.918
	100	43.81a-d	41.05a-f	51.02a	35.28b-k	49.30ab	44.092
	Mean	22.555	28.673	30.120	28.048	28.208	27.521
69	25	25.96f-y	25.03g-zA	25.71f-z	13.12u-zA	19.41l-zA	21.846
	50	24.99g-zA	22.10i-zA	29.91d-s	16.99q-zA	34.06c-m	25.610
	75	38.59a-g	32.84c-o	45.59abc	37.48a-i	31.58c-q	37.216
	100	29.84d-t	32.39c-q	30.65c-r	40.77a-f	38.61a-h	34.452
	Mean	29.845	28.090	32.965	27.090	30.915	29.781
Mean		23.465	24.369	27.492	25.455	28.535	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 21.60%.

Table 8. Interaction effect of N, P and soil water content on mean total plant N uptake (mg plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	28.43B	53.47yzAB	33.69AB	57.57xyzAB	51.21yzAB	44.874
	50	45.42zAB	51.24yzAB	70.29t-z	58.98w-zAB	68.55u-z	58.896
	75	78.09q-z	63.04v-zA	117.1g-n	61.06w-zA	70.48t-z	77.954
	100	76.11r-z	67.51u-z	73.90s-z	86.31n-x	81.54p-y	77.074
	Mean	57.013	58.815	73.745	65.980	67.945	64.700
23	25	45.76zAB	60.72w-zA	90.80l-w	118.20f-n	75.17r-z	78.130
	50	90.66l-w	88.00m-x	114.70h-o	77.81q-z	82.460-y	90.726
	75	81.91p-y	101.4j-t	107.50i-r	95.02k-v	115.00h-o	100.166
	100	98.72j-u	83.300-y	106.60i-r	119.80e-m	106.40i-s	102.964
	Mean	79.263	83.355	104.900	102.708	94.758	92.997
46	25	60.34w-zA	70.37t-z	88.07m-x	71.60t-z	65.37v-zA	71.150
	50	108.80h-q	105.40i-s	101.50j-t	112.40h-p	66.19u-z	98.858
	75	101.50j-t	130.70d-j	130.60d-j	125.00d-k	107.00i-r	118.960
	100	136.80c-i	135.10c-i	152.00bcd	125.40d-k	140.10b-h	137.880
	Mean	101.860	110.393	118.043	108.600	94.665	106.712
69	25	68.24u-z	69.53t-z	56.08xyzAB	69.95t-z	55.74xyzAB	63.908
	50	105.90i-p	98.71j-u	111.10h-p	126.50d-j	147.80b-g	92.702
	75	113.30h-p	184.20 a	150.70b-e	123.10d-l	148.80b-f	144.020
	100	186.20a	169.70ab	184.06a	192.10a	162.90abc	178.900
	Mean	118.410	130.535	125.620	96.038	128.810	119.883
Mean		89.137	95.775	105.577	93.332	96.545	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 12.41%.

Table 9. Interaction effect of N, P and soil water content on mean shoot P uptake (mg plant^{-1}) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	1.374B	1.813AB	3.519t-zAB	2.731yzAB	3.105x-zAB	2.504
	50	3.181w-zAB	4.070q-zA	4.183p-zA	4.679n-z	4.4700-z	4.117
	75	3.678s-zAB	3.134x-zAB	5.371l-x	4.276p-zA	6.430e-r	4.578
	100	4.819 n-z	9.134a-d	5.738j-w	7.018d-o	6.830d-o	6.708
	Mean	3.263	4.53775	4.70275	4.67600	5.20875	4.477
23	25	1.888AB	3.902r-zAB	4.921m-z	8.208a-j	3.536s-zAB	4.491
	50	3.173x-zAB	3.992q-zA	6.0087f-s	3.690s-zAB	5.440l-x	4.464
	75	3.107x-zAB	6.724d-p	6.987d-o	8.608a-f	10.41ab	7.162
	100	4.281p-zA	8.555a-g	8.718a-e	7.369d-m	8.255a-j	7.436
	Mean	3.112	5.79325	6.65868	6.96875	6.91025	5.888
46	25	2.431zA	3.199w-zAB	2.698yzAB	3.102x-zAB	3.418v-zAB	2.970
	50	4.075q-zA	5.176m-y	5.627k-x	8.696a-e	4.216 p-zA	5.558
	75	5.741j-w	6.447e-r	6.028h-t	6.037g-t	8.757a-e	6.602
	100	4.6210-z	8.598a-f	6.675d-p	8.056b-k	6.464e-q	6.883
	Mean	4.217	5.85500	5.25700	6.47275	5.71375	5.503
69	25	1.445B	3.061x-zAB	2.501zAB	3.440u-zAB	3.189w-zAB	2.7272
	50	3.645s-zAB	5.906i-v	5.978h-u	8.317a-i	4.677n-z	5.7046
	75	4.708n-z	7.859c-l	6.905d-o	6.397e-r	8.780a-e	6.9298
	100	8.477a-h	9.856abc	10.520ab	10.600a	7.212d-n	9.3330
	Mean	4.569	6.67050	6.47600	7.18850	5.96450	6.174
Mean		3.79025	5.714125	5.773608	6.3265	5.949313	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 17.14%.

The interaction effect of the three factors showed highest root P uptake at 23 kg N ha^{-1}, 40 kg P ha^{-1} and 100% FC water content increasing by 687.6% (7.283 mg plant^{-1}) over the control treatment levels. The highest root P uptake observed was at the relatively lower rate (23 kg N ha^{-1}) of applied N (Table 10). Fageria (2009) reported that if water flow does not supply the root requirements, nutrient absorption by the root at or near its surface will reduce its concentration and, consequently, uptake. Besides, he reported that P is an immobile nutrient in soil; thus, maintaining an adequate supply of moisture in the soil–plant system is essential for its movement to the root vicinity and its uptake.

Table 10. Interaction effect of N, P and soil water content on mean root P uptake (mg plant-1) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha-1)	Water content (%FC)	P (kg P ha-1)*					
		0	10	20	30	40	Mean
0	25	0.9247KL	1.671D-L	1.496E-L	1.551E-L	1.893A-J	1.507
	50	1.457F-L	2.224v-zA-I	2.744p-zABC	2.886o-zA	3.473h-q	2.557
	75	2.391t-zA-H	2.417t-zA-G	2.634q-zA-D	2.996o-y	4.009e-n	2.889
	100	2.144w-zA-J	3.239k-u	3.302j-t	3.435h-r	4.641c-f	3.352
	Mean	1.729	2.388	2.544	2.717	3.504	2.576
23	25	1.340I-L	1.451G-L	1.912A-J	2.179w-zA-J	2.185w-zA-J	1.813
	50	2.299u-zA-I	2.444s-zAF	3.078n-w	1.881B-J	2.467 r-zA-E	2.434
	75	3.060n-x	3.665g-p	3.341j-t	2.859o-zAB	2.641q-zA-D	3.113
	100	2.023y-z A-J	2.717p-zABC	4.504c-g	4.383c-h	7.283a	4.182
	Mean	2.181	2.569	3.209	2.823	3.644	2.886
46	25	0.7773L	1.227JKL	1.414H-L	1.960zA-J	1.785C-K	1.433
	50	1.537E-L	3.062n-w	2.124w-zA-J	2.090w-zA-J	3.801f-o	2.523
	75	1.927zA-J	2.697p-zABC	3.191m-v	4.211c-j	3.211l-v	3.047
	100	4.076d-m	4.99 cd	6.040b	4.163c-k	4.770cde	4.808
	Mean	2.079	2.994	3.192	3.106	3.392	2.953
69	25	1.402H-L	2.387t-zA-H	2.224v-zA-I	2.026yzA-J	2.069x-zA-J	2.022
	50	2.599q-zA-D	2.700p-zABC	2.987o-y	2.304u-zA-I	3.196m-v	2.757
	75	2.131w-zA-J	2.834o-zAB	4.381c-h	5.072c	4.154c-l	3.714
	100	2.010yzA-J	2.908o-z	3.407i-s	4.347c-i	4.784cde	3.491
	Mean	2.036	2.707	3.250	3.437	3.551	2.996
Mean		2.006	2.665	3.049	3.021	3.523	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 12.84%.

Table 11. Interaction effect of N, P and soil water content on mean total P uptake (mg plant-1) at harvest (45 DAS) of maize grown on Fluvisols under greenhouse condition.

Nitrogen (kg ha-1)	Water content (%FC)	P (kg P ha-1)*					
		0	10	20	30	40	Mean
0	25	2.990E	3.48 4B-E	5.015xyzA-D	4.282zA-E	4.998x-zA-D	4.153
	50	4.638yzA-E	6.294s-zA	6.927q-z	7.564p-x	7.943l-w	6.673
	75	6.070t-zAB	5.552u-zA-D	8.005k-v	7.271q-y	10.440e-n	7.468
	100	6.963q-z	12.370b-f	9.041g-r	10.450e-n	11.470c-h	10.059
	Mean	5.165	6.924	7.247	7.392	8.713	7.088
23	25	3.228CDE	5.354v-zA-D	6.833q-zA	10.390e-o	5.722u-zABC	6.305
	50	5.472v-zA-D	6.430r-zA	9.165g-r	5.5701u-zA-D	7.907l-w	6.909
	75	6.167t-zAB	10.390e-o	10.330e-o	11.470c-h	13.050a-e	10.281
	100	6.304s-zA	11.270c-i	13.220a-d	11.750c-g	15.540 a	11.617
	Mean	5.293	8.361	9.887	9.795	10.555	8.778
46	25	3.209CDE	4.426zA-E	4.111A-E	5.062x-zA-D	5.203w-zA-D	4.402
	50	5.612u-zABC	8.238j-u	7.751n-x	10.790d-j	8.017k-v	8.082
	75	7.668o-x	9.144g-r	9.219g-q	10.250f-p	11.970c-f	9.650
	100	8.697i-t	13.590abc	12.710b-f	12.220c-f	11.230c-i	11.689
	Mean	6.297	8.850	8.448	9.581	9.105	8.456
69	25	2.848DE	5.448v-zA-E	4.725yzA-E	5.466v-zA-D	5.258v-zA-D	4.749
	50	6.244s-zA	8.607i-t	8.965h-s	10.620d-l	7.873m-w	8.462
	75	6.839q-zA	10.690d-k	11.290c-i	11.470c-h	12.930b-f	10.644
	100	10.490e-m	12.760b-f	13.930abc	14.940ab	12.000c-f	12.824
	Mean	6.605	9.376	9.728	10.624	9.515	9.170
Mean		5.840	8.378	8.828	9.348	9.472	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 12.26%.

Table 12. Interaction effect of N, P and soil water content on mean soil residual P (mg kg^{-1} soil) at harvest (45 DAS) of maize grown on under greenhouse condition.

Nitrogen (kg ha^{-1})	Water content (%FC)	P (kg P ha^{-1})*					
		0	10	20	30	40	Mean
0	25	3.770EF	4.107C-F	4.293A-F	5.683m-w	6.827g-n	4.9360
	50	3.917DEF	4.283A-F	4.383yzA-F	4.340zA-F	8.267a-e	5.0380
	75	4.370yzA-F	6.393i-r	6.737g-o	6.887f-m	8.620a	6.6020
	100	3.983DEF	4.697u-zA-E	7.113e-	7.567a-i	8.597ab	6.3914
	Mean	4.010	4.870	5.632	6.119	8.079	5.742
23	25	4.293A-F	5.507o-zA	5.437p-zAB	7.440a-j	8.343a-d	6.2040
	50	4.420xyzA-F	5.147s-zCD	6.233j-s	7.690a-h	8.343a-d	6.3666
	75	4.436w-zA-F	4.543v-zA-E	4.870t-zA-E	7.220d-l	6.787g-n	5.5712
	100	3.200F	4.223B-F	4.687u-zA-E	5.593n-z	6.487h-q	4.838
	Mean	4.087	4.855	5.307	6.988	7.490	5.745
46	25	4.243A-F	4.640u-zA-E	5.573n-z	6.627h-p	8.080a-f	5.8326
	50	4.333zA-F	4.653u-zA-E	5.820m-u	5.163r-zA-D	5.487o-zA	5.0912
	75	3.947DEF	3.827EF	5.293q-zABC	5.660m-x	6.527h-q	5.0498
	100	3.667EF	6.707g-o	7.570a-i	8.477abc	8.600ab	7.0042
	Mean	4.046	4.958	6.064	6.482	7.174	5.745
69	25	3.210F	6.060l-t	6.617h-p	7.477a-j	7.890a-g	6.2508
	50	3.940DEF	4.033C-F	4.660u-zA-E	5.763m-v	6.127k-s	4.9046
	75	4.407xyzA-F	4.767u-zA-E	5.140s-zA-D	6.717g-o	7.300c-l	5.6662
	100	4.060C-F	5.613n-y	6.887f-m	7.373b-k	6.493h-q	4.9626
	Mean	3.904	3.715	5.826	6.833	6.953	5.446
Mean		4.012	4.560	5.707	6.6055	7.424	

*Three factor interaction means followed by the same letter (s) are not significantly different at P > 0.01. Coefficient of variation (CV) = 8.21%.

Maize total plant P uptake like that of N was significant (P ≤ 0.01) due to the three factor interaction of N, P and water content. The highest response was obtained at the interaction rate of 23 kg N ha^{-1}, 40 kg Pha^{-1},100% FC having increased by 419.7% (Table 11). It is generally believed that the greatest benefit from fertilizer application can be derived under irrigated conditions, where water supply is least likely to limit nutrient uptake (Hussaini, 2008). Seyyed (2012) also concluded similar results from another experiment in Pakistan. Besides, FAO (2006) indicated that in dry soil conditions, the amount of sparingly soluble nutrients, such as P, is reduced and plants are unable to absorb them in required quantities.

Phosphorus remained in soil after harvest

The interaction effect of the three treatments showed significantly (P ≤ 0.01) higher soil remained P (increased by 4.85 mg P kg^{-1} i.e. 128.6% at the interaction of 0 kg N ha^{-1}, 40 kg P ha^{-1} and soil water content of 75% FC compared to the control plot). This was followed by other higher significant results of P remained in soil at the interaction rates of 46 kg N ha^{-1}, 40 kg P ha^{-1} and soil water content of 100% FC and some other interaction treatments that were significantly (P ≤ 0.01) different compared to the control plot (Table 12). Soil remained P showed increasing trend from 0 kg P ha^{-1} to 40 kg P ha^{-1}at all N and soil water content levels. At the 40 kg P ha^{-1} treatment P remained in the soil was higher at 0 N ha^{-1} and soil water content of 50-75% FC then showed decreasing trend when applied N increased to 69 kg N ha^{-1} at soil water content of 25% FC. Higher soil remained P at higher level of applied P and at lower rates of N and mostly at the lower rates of soil water content was observed. This may be due to lower uptake of P by the maize plant in the absence of N and water and on the contrary because of higher uptake of P by the plant in the presence of N and water as well as their interaction effects with applied P on P uptake by maize plant. This is in confirmation to that of Chirnogeanu *et al.* (1997) who had reported increased P mobility and its content in soil with increasing rates of P fertilizer when N and P were applied under irrigated condition in Romania.

Conclusion

Soil water content, applied N and P promoted growth as well as N and P uptakes of maize. Generally, plant height, biomass dry matter weight as well as N and P uptakes gave higher response to the three factors at the higher application rates. For each N and P level, height, dry matter weight and uptakes of N and P increased as soil water content increased. This positive response in the parameters may be partly because of the low N and P content of the light textured soil and partly due to the application of water that might have increased the availability of nutrients. Higher remained P in soil after harvesting was observed at the highest applied P rate, part of which remained unutilized by maize. Higher amount of soil remained P at lower applied N and soil water content rates was observed as the result of lower uptake of P by maize when N and water were not optimum which resulted in high P remaining in the soil. Fertilizer application at the interaction rates of 30 kg P ha^{-1} and 46 kg N ha^{-1} can be recommended for maize at early vegetative growth stage on Fluvisols in Agulae-Womberta area when soil water content is at field capacity. However, further studies under field condition especially at reproductive stage of the crop are necessary for optimum water and nutrient management for maize in the study area. Fertilizer study at vegetative as well as reproductive stages is important because maize has two peak plant nutrient demands at these growth stages.

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