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EFFECTS OF DRAIN DEPTH OF VERTISOLS, NITROGEN SOURCE AND TIME OF APPLICATION ON NUTRIENT UPTAKE BY MAIZE (*Zea mays* L.) IN WESTERN ETHIOPIA

Tadesse Debele[1*] and Birhanu Iticha[2]

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Abstract

Nitrogen is the most limiting plant nutrient in Vertisols in western Ethiopia. Vertisols properties and management factors as well as fertilizer source and time of application could influence nutrient uptake by crops. With this view, a field study was conducted at Ambo Agriculture Research Centre experimental site during the main cropping season of 2013-2014, with the aim to determine interactive effects of drain depth of Vertisols, N source and time of N application on nutrient uptake by maize. Treatments comprised five drain depths (0, 15, 30, 45 and 60 cm), two N sources (urea and ammonium sulfate) and two timings of N applications (twice and thrice). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Result showed that there was significant interactions effect of drain depths, N source and time of application on the concentration of nutrients in the grain and stover. The NH_4-N uptake by maize was found to be significantly better than NO_3-N utilization by maize. Grain and stover uptake of N, P and K by maize increased with drain depth and thrice split application of ammonium sulfate. It is concluded that draining off excess soil water from the rhizosphere is the key factor in improving nutrient uptake by maize in Vertisols in Ambo area.

Keywords: Drain Depth, Vertisols, Ammonium Sulfate, Urea, Nutrient Uptake, *Zea mays*

[1]Department of Plant Sciences, College of Agriculture and Veterinary Sciences, Ambo University, P.O. Box 19, Ambo, Ethiopia
[2]Department of Soil Resource and Watershed Management, Wollega University, P. O. Box 395, Nekemte, Ethiopia

*Corresponding author's email: tadesse_2007@yahoo.com (Tadesse Debele)

Introduction

Ethiopia is ranked 3rd in terms of acreage of deep, black, cracking, clay soils (Vertisols) in Africa, after Sudan and Chad, estimated at 12.6 million ha with 7.6 million ha in the highlands (1500 meter above sea level) (Berhanu, 1985). The ecology of these plateaus is characterized by high annual rainfall, in excess of 900 mm, and moderate temperatures, which leads to relatively low evaporation, particularly during the growing period. Moderate to severe waterlogging and serious water-borne soil erosion are common features in these Vertisol areas. About 2.21 million ha of the highland Vertisols are cropped and some 6 million ha are left under native pasture because of severe drainage problems in the main rainy season (Berhanu, 1985; Jutzi *et al.*, 1987).

Bull (1988) estimated that Ethiopia Vertisols can produce about 12 million tons of food grain if improved management practices are widely adopted. Despite the big potential of the Vertisols, except, the 25%, which is cultivated, the rest are mostly in bottom lands, get flooded, remain uncultivated and are mainly used for dry season grazing. The productivity of Vertisols can be increased by surface drainage. According to Kanwar *et al.* (1982), the key to improved Vertisols utilization for human food production is effective surface drainage. Removal of excess water during the wet season is one of the most crucial management practices for Vertisols, which differentiates them from most other soils.

In Ethiopian Vertisols, N is the most universally deficient plant nutrient element (Engdawork, 2002; Mohammed, 2003). The crop response to N applications in Vertisols is closely linked to soil moisture variations and, hence to rainfall pattern (IBSRAM, 1989; ICRISAT, 1989). According to Deckers *et al.* (2001), total N is universally deficient in tropical Vertisols, usually varied from 0.02 to 0.08% and rarely exceeds 1%. Likewise, Berhanu (1985) also reported the total N contents of Vertisols of the central highlands and eastern lowlands of Ethiopia varied from 0.08 to 0.22%. The low N content caused by denitrification losses resulting from poor drainage, leaching losses and less OM input. In this respect, management measure that can alleviate waterlogging conditions could be a possible means of reducing denitrification losses.

The use of drainage furrows for excess surface water drainage had been reported to improve maize yields and higher maize yields were also observed when the drainage furrows were combined with fertilizer N (Ikitoo *et al*., 2003). Ahmed (1988), reporting on Vertisols management under humid tropical conditions, and Muchena and Ikitoo (1992), working in Kenya, observed increases in yields of field crops grown in Vertisols because of draining excess water. Draining excess water with furrows to a depth of 40 cm was found essential for successful maize production in Vertisols under sub-humid conditions (Sigunga *et al*., 2002). Thus, management technologies for crop production in Vertisols should be geared towards the control of water dynamics and improving soil fertility (Probert *et al*., 1987; Ahmed, 1988).

In Ambo, drainage is a serious constraint to maize production in Vertisols during rainy seasons. Although many works have been done on Vertisols management, no attention has been given on drainage conditions of Vertisols in relation to nutrient uptake by maize. Therefore, the objectives of this study were to determine the effect of drain depth and N source and time of application on nutrient uptake by rain-fed maize grown on Vertisols in Ambo.

Materials and Methods

Description of the study area

The experiment was conducted at Ambo Agriculture Research Centre experimental site during the main cropping season in 2013. Ambo Agriculture Research Centre is located at 8°55' north and 38°07' east at an altitude of 2225 meter above sea level. Climatic data of the experimental site as obtained from nearby weather stations is given in Table 1. The soil of the study site was classified as Vertisols (Morton, 1977) with low soil N status (Engdawork, 2002). The site is characterized by a slope of less than 2%.

Table 1. Monthly rainfall (mm), minimum, maximum and avergae air temperature of Ambo Agriculture Research Centre for 2013 cropping season.

Month	Rainfall (mm)	Minimum air temperature (^{0}C)	Maximum air temperature (^{0}C)	Mean air temperature (^{0}C)
January	3.5	9.8	27.6	18.4
February	13.5	10	28.8	17.6
March	13.6	11.8	29.5	20.7
April	103.8	11.2	29.4	18.3
May	136.5	11.6	28.3	19.9
June	287.7	10.5	28.1	19.3
July	269.9	10.6	28	19.3
August	173.7	9.8	25.7	17.6
September	114.3	9.6	25.3	17.5
October	123.7	8.2	26.3	17.3
November	2.7	8.3	26.9	17
December	18	6.8	26.6	16.7
Total/Mean	1260.90	9.85	27.54	18.30

Field experiments

A field experiment was conducted on waterlogged Vertisols to test the effect of drain depth on nutrient uptake by maize during the main cropping seasons. The experiment was laid out in a Randomised Complete Block Design (RCBD) with three replications. The treatments comprised of five drain depths (0, 15, 30, 45 and 60 cm), two N sources and time of applications. The two N sources (urea and ammonium sulphate) were combined in a complete factorial arrangement. Nitrogen from urea and ammonium sulphate (AS) was applied at the recommended rate of 92 kg N ha^{-1} for maize, and all treatments received the recommended phosphorus rate of 20 kg P ha^{-1} in the form of triple super phosphate (TSP). Urea and AS fertilizers were applied in split, viz. half at sowing and half at 35 days after sowing when maize was at knee-height stage, and 1/3 at sowing, 1/3 at 35 days after sowing when maize is at knee-height stage and 1/3 at flowering stage of maize crop, respectively. All TSP was applied in a band at sowing. Prior to treatment application, soil samples from the site were collected for physico-chemical analysis.

Cultural practices and planting materials

The cultivation of land in the study area starts in the months March and April during the short rainy seasons when workability of Vertisols is relatively good. Land cultivation is almost exclusively done using oxen-drawn implements. For maize, two or three passes are considered sufficient. Open drains were formed manually using hoes and spade, measured and adjusted to the required drain depths. Highland maize hybrid Jibat (AMH851) released for highland agroecologies, widely grown the study area. The maize hybrid was planted in 6 rows of 5.0 m long with inter- and intra-row spacing of 0.75 and 0.25 m, respectively. Plots within a block were separated by 1 m space and blocks separated by a 2 m path. One plant hill^{-1} was maintained after thinning, giving plant population of 53,333 plants ha^{-1}. The recommended weed control practice for maize i.e., twice hand weeding at 30 and 55 days after sowing followed by slashing at milk stage was adopted.

Plant sampling and analysis

Samples for plant tissue analysis were taken from each of the plots, dissected into grains and stover. Dry matter (DM) was determined by drying sub-samples of grains and stover in the oven at 70 ^{0}C for two to three days to attain constant weight. The sub-samples were ground and analyzed for N, P, and K contents. Total nitrogen concentration was determined by the micro-Kjeldahl method (Bremner, 1965). For the determination of the remaining elements, plant samples were first subjected to wet digestion (Mehlich, 1984). P content was determined colorimetrically using a spectrophotometer. The procedure involved the use of Vanado-molybdate yellow method (Murphy and Riley, 1962). A flame photometer was used for the determination of K (Heald, 1965).

The total N, P and K uptake in stover and grains were calculated by multiplying the N, P and K contents by the respective stover and grain yields ha^{-1}. Total N, P and K uptake, by the whole plant were determined by summation of the respective grain and stover N, P and K uptakes on hectare basis.

Soil sampling and analysis

A total of five representative composite soil samples were randomly collected from each block from 0-30 cm soil profile before drainage depth was made. An auger was used to sample five randomly selected spots per each soil depth. The soil of these sub-samples was mixed thoroughly, dried at room temperature, ground and sieved through a 2 mm screen for physico-chemical analysis; whereas for OC and total N determination soil samples were passed through 0.5 mm sieve.

Laboratory analysis was carried out to characterize the soil physical and chemical properties that are considered important for crop management. Soil particle size was analyzed by the Bouyoucos hydrometer method following the procedure described by Day (1965). After harvesting of maize crop, soil samples were collected from all the plots from 0-15, 15-30, 30-45 and 45-60 cm depth and analyzed for the aforementioned chemical properties.

Soil pH was measured potentiometriclly using a pH meter with combined glass electrode at soil: water ratio of 1:2.5 as described by Carter (1993). Organic carbon (OC) content of the soil samples was determined using the wet oxidation method (Walkley and Black, 1934) where the carbon is oxidized under standard condition with potassium dichromate in sulfuric acid solution. Finally, the organic matter (OM) content of the soil was calculated by multiplying the percent OC by 1.724. The total N content of the soil samples was determined by the Kjeldahl method using micro-Kjeldahl distillation unit and Kjeldahl digestion stand (Jackson, 1958). Available P of soil samples were determined by the Olsen method using $NaHCO_3$ as extracting solution (Olsen *et al*., 1954). Exchangeable K in soil samples was determined from the leachate of ammonium acetate (NH_4OAc) solution at pH 7.0 by flame photometer (Rowell, 1994).

Statistical analysis

All the data collected were managed properly using the Excel computer software. The collected data was subjected to the analysis of variance using the SAS program version 8.2 (SAS Institute, 2001). Treatment means for each parameter were separated by Duncan's Multiple Range Test (DMRT) and Least Significant Difference (LSD) test at P = 0.05.

Results and Discussion

Some physical and chemical topsoil characteristics of these Vertisols before commencement of the trials are presented in Table 2.

Table 2. Selected physico-chemical properties of Vertisols of the experimental site before the formation of drainage depth in 0-30 cm of the soil profile.

Block	Particle size (%)			pH (H_2O)	OM (%)	Total N (%)	AP (mg kg^{-1})	Exch. K (mg kg^{-1})
	Sand	Silt	Clay					
1	12.14	21.51	66.35	6.13	2.60	0.12	6.03	47.74
2	10.74	22.83	66.43	6.14	2.63	0.11	6.02	46.62
3	12.27	23.45	64.28	6.22	2.61	0.13	6.00	48.27
Mean	11.72	22.60	65.69	6.16	2.61	0.12	6.01	47.54

OM = Organic matter; AP = Available (Olsen) phosphorus; Exch. K = Exchangeable potassium

Effect of drain depth

The analyses of variance showed that drain depths, nitrogen fertilizer source and time of application had significant effect (P < 0.05) on grain, stover and total biomass N, P and K uptake of maize. The interaction between drain depths and nitrogen source was also significant (P<0.05) influencing maize grain, stover and total biomass N, P and K uptake of maize, while the interaction between drainage and time of N application should a non-significant effect on N, P and K uptake of maize (Table 3, 4 and 5).

Table 3. Interaction effect of drain depth and nitrogen source on grain and stover N uptake of maize grown on Vertisols.

Drain depth (cm)	N uptake (kg ha^{-1})					
	N sources					
	Urea			AS		
	Grain	Stover	Total	Grain	Stover	Total
0	31.16g	30.26g	61.42g	42.31f	35.85f	78.16f
15	40.65f	39.42e	80.07f	49.45e	44.92d	94.37e
30	55.24de	45.58d	100.82e	60.64cd	50.23c	110.87d
45	64.32bc	52.90c	117.22cd	73.54a	56.70b	130.24ab
60	70.67ab	53.20c	123.87bc	75.18a	62.45a	137.63a
CV (%)	10.96	9.89	8.74	10.96	9.89	8.74
LSD (0.05	6.78	3.36	8.37	6.78	3.36	8.37

Means within a column followed by the same letter(s) are not significantly different at 5% probability

Table 4. Interaction effect of drain depth and nitrogen source on grain and stover P uptake of maize grown on Vertisols.

Drain depth (cm)	P uptake (kg ha^{-1})					
	N sources					
	Urea			AS		
	Grain	Stover	Total	Grain	Stover	Total
0	5.61f	4.67h	10.28f	8.87e	7.62f	16.49e
15	7.26ef	5.42g	12.68f	12.81cd	9.10d	21.91d
30	9.35e	8.45e	17.80e	14.34bc	11.15b	25.49c
45	11.90d	9.27d	21.17d	15.25b	13.55a	28.80b
60	13.20bcd	10.25c	23.45cd	17.48a	14.10a	31.58a
CV (%)	11.67	10.17	9.79	11.67	10.17	9.79
LSD (0.05)	2.19	0.63	2.44	2.19	0.63	2.44

Means within a column followed by the same letter(s) are not significantly different at 5% probability

Table 5. Interaction effects of drain depth and nitrogen source on grain and stover K uptake of maize grown on Vertisols.

Drain depth (cm)	K uptake (kg ha^{-1})					
	N sources					
	Urea			AS		
	Grain	Stover	Total	Grain	Stover	Total
0	30.17f	40.95e	71.12f	35.42ef	53.80cd	89.22ef
15	37.14e	51.35d	88.49ef	45.26d	58.89bc	104.15cde
30	45.67d	53.22cd	98.89de	57.33bc	64.16ab	121.49abc
45	51.97c	58.39bcd	110.36cd	62.64ab	70.10a	132.74ab
60	56.19c	60.08bc	116.27bcd	65.89a	70.32a	136.21a
CV (%)	10.18	9.25	14.94	10.18	9.25	14.94
LSD (0.05)	5.39	6.95	8.35	5.39	6.95	8.35

Means within a column followed by the same letter(s) are not significantly different at 5% probability

The grain and stover, N, P, K, and total uptake parameters increased with furrow depths where the maximum uptakes as recorded at 60 cm deep drain depth and the minimum in undrained plots. Under both urea and AS fertilizer application, the N, P and K uptake of maize increased progressively with increased drainage depth. But, application of AS showed more pronounced N, P and K uptake than urea application (Table 3, 4 and 5). Urea is susceptible to enormous losses if drainage depths were not provided. These results are corroborated by Sigunga *et al.* (2002) who reported significantly higher N, P and K uptake in plants with 40 cm and 60 cm deep furrows with fertilizer AS suggests a more favorable root environment in the drained plots that lead to general crop vigor and higher nutrient demand by the crop. They reported also that drain depths of Vertisols created favorable conditions for growth and development of maize by removing excess water from the soil and making good aeration to the soil thereby considerably increased the N, P and K uptake of maize as compared to maize grown without drainage.

Effect of nitrogen source

Application of different source of fertilizer N increased nitrogen content and the uptake of other nutrients. The highest grain N (75.18 kg ha^{-1}) and stover N (62.45 kg ha^{-1}) uptakes were obtained with AS fertilizer application at a drain depth of 60 cm and the least uptake recorded from the undrained plots with urea application (Table 3). The results clearly showed the positive effects of drainage depths on maize grain and stover yields and the improvement of grain and stover N uptakes with drain depths. Similarly, the highest grain P (17.48) and stover P (14.10) uptakes were observed with AS application at drain depth of 60 cm while the lowest grain and stover P were recorded from undrained plot with urea application. Furthermore, the grain and stover P uptakes exhibited positive responses to drain depths where the maximum plant P uptake was observed at drain depths of 45 and 60 cm. Maize grain assimilated much of P than stover. This result is in agreement with Skowronska and Filipek (2010) who reported that maize grain was the main accumulation pool for element P. The uptake of potassium by maize plant was also influence by drain depth. On the other hand, the highest grain K (65.89 kg ha^{-1}) and stover K (70.32 kg ha^{-1}) uptake was observed with fertilizer AS application at deep drain depth of 60 cm, followed by 45 cm drain depth. The total K uptake also increased with drain depth and the maximum was observed at deep drain depth of 60 cm. This result is in line with Sigunga *et al*. (2002) who reported that total K uptake was highest at deep drain depth of 60 cm coupled with fertilizer AS.

Effect of time of nitrogen application

Thrice split application of N source resulted in higher grain, stover and total biomass N, P and K uptakes than twice application (Fig. 1). The grain, stover and total biomass N uptake of maize rose from 51.40, 43.72 and 95.12 kg with twice split application of nitrogen fertilizers source to 61.23, 50.58 and 111.81 kg ha^{-1} with thrice split application, respectively. Similarly, the grain, stover and total biomass P uptake increased from 9.25, 7.10 and 16.35 kg with twice split application of nitrogen fertilizers to 13.96, 11.62 and 25.58 kg ha^{-1} with thrice split application, respectively. Similar result is reported by Sigunga *et al.* (1997); thrice split application of N sources enhanced uptakes of N and P by grain and total dry matter of maize grown on a Vertisols. In case of maize grain, stover and total biomass K uptake rose from 45.0, 53.95 and 98.95 kg ha^{-1} with twice split application of nitrogen fertilizers sources to 52.54, 62.30 and 114.84 kg ha^{-1} with thrice split application, respectively. These results are in agreement with Sigunga *et al*. (1997) who reported that thrice split application of N sources improved uptake of K.

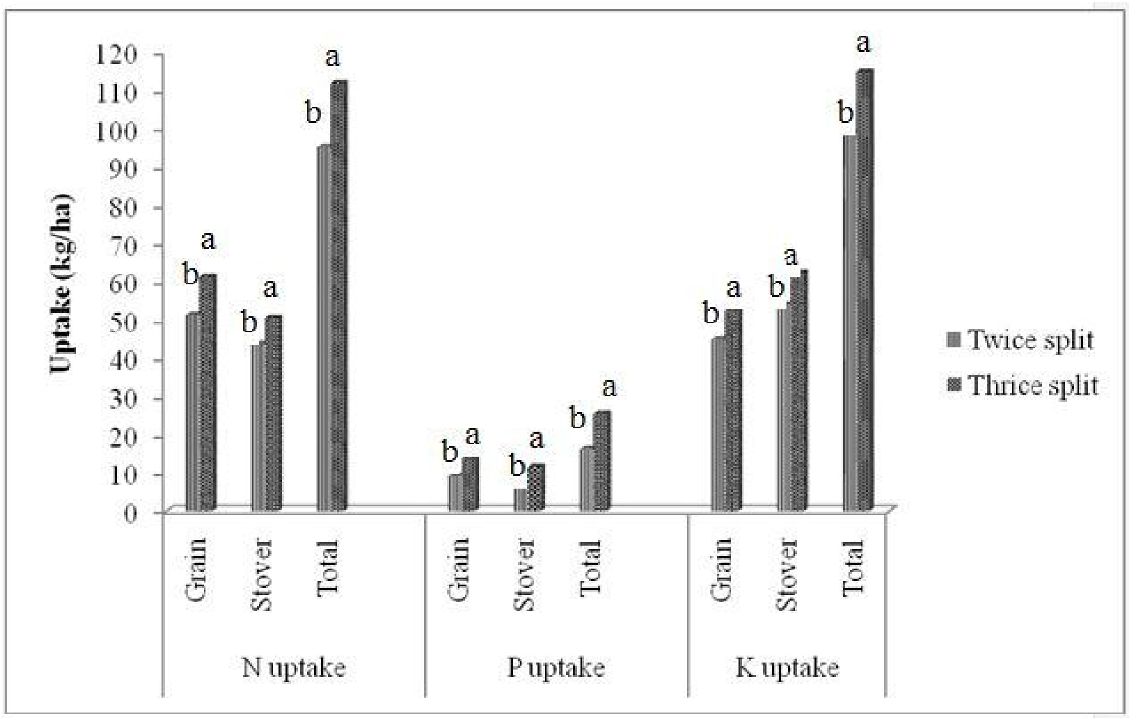

Fig 1. Effects of nitrogen time of application on grain, stover and total biomass N, P and K uptake of maize grown on Vertisols. Bars for each parameter with different letters are significantly different at 5% probability.

Conclusion

Nutrient uptake by crops is influenced by interacting soil, climatic and management factors as well as fertilizer characteristics. The grain and stover N, P, and K uptake of maize were significantly improved by drain depth. Ammonium-N source was found to be significantly superior to the NO_3-N source in terms of grain and stover uptake of N, P, and K of maize in situation where drain depth was provided. Nitrate-N source is susceptible to enormous losses if drains of at least 45 cm depth are not provided. It is concluded that provision of drains 45 and 60 cm deep with thrice split application of ammonium sulfate is essential for successful maize production in waterlogged Vertisols in Ambo area.

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