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Influence of UREA and NPK Fertilizers on Selected Soil Properties that Could Control Nutrient Uptake in Local Maize Variety in a Semi-Arid Area of Tanzania

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ABSTRACT: The decline in agricultural production in different regions of the globe has necessitated the use of fertilizers. However, inorganic fertilizers are blamed to affect soil properties consequently affecting crop performance. This paper aimed to investigate the influence of UREA and NPK fertilizers on soil properties that could control nutrient uptake in regional maize variety in Tanzania using appropriate standard methods. Differences in soil properties on application of UREA, NPK and control (no fertilizer) were observed before and after growing maize. Data obtained in UREA, NPK and Control were Soil pH (8.48 ± 0 – 8.22 ± 0.08), (8.48 ± 0 – 7.3 ± 0.25), (8.48 ± 0 – 8.72 ± 0.09); Bulk density (1.39 ± 0.014 – 1.40 ± 0.008), (1.39 ± 0.029 – 0.04 ± 0.010), (1.38 ± 0.035 – 0.21 ± 0.035); Soil moisture content (15.25 ± 0.30 – 10.86 ± 1.12), (15.27 ± 0.39 – 2.67 ± 0.89), (15.14 ± 0.87 – 17.19 ± 3.41); Water holding capacity (0.27 ± 0.02 – 1.13 ± 0.09), (0.28 ± 0.02 – 1.11 ± 0.27), (0.28 ± 0.02 – 1.60 ± 0.17); Porosity (38.45 ± 2.07 – 45.64 ± 0.34), (39.67 ± 1.26 – 97.11 ± 3.12), (38.68 ± 0.34 – 91.38 ± 1.45) respectively. NPK application improved aeration, lowered soil pH and compaction but promoted dryness. On the other hand, the use of UREA resulted in compaction of the soil, lowered aeration and water holding capacity. This is an indicative of interference with water, nutrient and air availability. Revisitation of formulations of UREA and NPK fertilizers is recommended considering the global soil water shortage.

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Nutrient availability in soils is important for quality and sustainable productivity of crops. However, scholars in different parts of the world reported on continued decrease in agricultural outputs (Ray *et al.*, 2022; Santini *et al.*, 2022). For example, worldwide sub-Saharan Africa ranked the least in agricultural production due to factors identified as poor soil quality, changing climate and crop diseases (Bjornlund *et al*., 2020). The poor quality of soils in sub-Saharan Africa is mainly contributed by shortages of nutrients in soils among other factors (FAO (Food and Agriculture Organization), 2022). Low soil nutrients were reported in West Africa, East Africa, the Great Lakes region and Ethiopia (World Bank, 2014). For example, in Ethiopia, Kenya and Tanzania low soil levels of N, P, S, Cu, Mo, Mg, Fe, Zn, C, Ca, K and B have been reported (Mugo *et al.*, 2020; Merumba *et al.*, 2020; Gadisa, 2021; Mng'ong'o *et al.*, 2021). Fertilizers are natural or synthetic materials, organic or inorganic applied to

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soil or plant tissues to supply nutrients (Wang *et al*., 2018). Elsewhere inorganic and organic fertilizers, manure, crop residues and treated wastes are constantly added to soils (Stewart, 2020; Mng'ong'o *et al*., 2021). These substances add nutrients to soils ultimately promoting seed germination, plant resistance to harsh conditions, vigorous growth and productivity as they contain bioactive molecules with beneficial effects (Abebe *et al*., 2022). In sub-Saharan African countries such as Uganda, Kenya, Ethiopia, Nigeria, Rwanda, Ghana, Mozambique and Benin; Nitrogen, Phosphorus and Potassium (NPK) grade, Diammonium Phosphate (DAP) and UREA have been extensively used in order to replenish soil nitrogen and phosphate (André, 2009; Solomon *et al*., 2020). Malawi has the highest inorganic fertilizer application of 146 kg/ha, followed by Nigeria 128 kg/ha, Ethiopia 45 kg/ha, Tanzania 16 kg/ha, Niger 4.5 kg/ha and Uganda 1.2 kg/ha (Teklu, 2016). However, negative effects on soils due to application of inorganic fertilizers have been reported in different regions (Nabyonga *et al*., 2022).

Constant use of synthetic fertilizers contributes to soil compaction which is associated with thick layers and compressive forces that negatively influence almost all soil properties (Mari *et al*., 2008; Weisskopf *et al*., 2010). Compaction of soils changes the structure by breaking down aggregate units and decreasing pore space size between particles (Pahalvi *et al*., 2021). Also, an excessive use of inorganic fertilizers promotes heavy metal pollution, lowers soil pH and kills countless microbial populations (Dative and Xavier, 2018). According to UNDP (United Nations Development Program) and (FAO) (1983) Dodoma District is a semi-arid area with poor soil formations and low nutrients. With this background, application of inorganic fertilizers to improve the quality of soils cannot be avoided in the area. The objective of this paper was to investigate the influence of UREA and NPK fertilizers on selected soil properties that could control nutrient uptake in a local variety of maize (SC 419) in a semi-arid area of Tanzania.

MATERIALS AND METHODS

The Study Area: The study was carried out at the University of Dodoma which is found in Dodoma District in the central part of Tanzania. Dodoma District is located at 6° 9' 40.2624" S and 35° 44' 43.5336" E. The area is typically semi-arid with an average annual temperature of 22.6°C and little rainfall of about 447 mm throughout the year (World Meteorological Organization, 2022). The soil is characterised by textural classes ranging from coarse sands, reddish loamy to heavy clays, with scarce moisture, unstable aggregates that are susceptible to erosion. Additionally, some parts of the region are dominated by soil pH of 7.5 and hardy sub-soils which are likely to hinder penetration of deep plant roots (Msanya *et al*., 2018). The chief vegetation is woodland and wooded grass. The main economic activity in Dodoma is agriculture; crops cultivated include maize, grapes, nuts, tobacco and beans (Msanya *et al*., 2018). The University of Dodoma was suitable for this study due to availability of space for conducting pot experiments for growing maize and a constant supply of water for irrigation.

Study Design: Methods outlined by Baijukya (2020) were used to grow maize in plastic containers. Eighteen containers, each with a diameter of 60 cm, 30 cm top-down dimension to capture the rooting zone of most crops were used. Each container had four holes at the bottom. Fresh soils dark in colour, collected under canopy trees were put in the 18 containers after being moistened for 24 hours before sowing of maize seeds. In this study a local variety of maize (SC 419) purchased from Seed Co Tanzania was used. The seeds were soaked in water for 12 hours before sowing. Seven seeds were sown in each container though only five were retained after germination preferably 30 cm apart.

Fertilizer Application (UREA/NPK) and Fertilizer-Free in Growing Maize Plant: Each of UREA (46%) and NPK (25-5-5-3S) fertilizers were separately applied to six containers as per manufacturer's instructions. This was done by separately putting 10 g UREA and NPK fertilizers in holes that were dug at 5 cm from maize plant, which were then covered with soils on top. The remaining six containers were not fertilized since they served as control. All sown seeds were watered early in the morning and/or late in the evening as necessary.

Sample Collection: Just before commencement of flowering stage due to limitation of time, all maize plants were uprooted from the containers for analysis of the underlying soils. Soil in each container was thoroughly mixed from which 10 g was taken, air-dried, loosened and sieved through a 2 mm sieve. The collected soil samples were immediately packed in thick-gauze polythene bags, labelled and taken to Biology laboratory of the University of Dodoma and stored for the various analyses.

The soil samples were used for analysis of soil pH using the methods outlined by Mclean (1982). Soil samples for bulk density determination were collected using a steel core cylinder measuring 6.4 cm × 9.8 cm. In each pot the core cylinder was carefully driven into the top soil (0-10 cm) to obtain undisturbed sample of organic soil. Another set of soil sample was taken from 10-20 cm depth and the last from 20-30 cm. The bulk density of the soil was determined by the use of known core volume method (Blake and Hartage, 1986). The soil cores were oven dried to constant weight, and then bulk density was computed. Soil moisture content was measured using the method explained by Klute (1986) under constant pressure ranging from 0.1 to 15 atm. Water holding capacity was determined by measuring the soil moisture at the field capacity and at permanent wilting point. The difference between those two soil moisture values was the water holding capacity (Assi *et al*., 2018). Porosity of all soil samples was measured using the saturation method which involved pouring of water to the top of all soil samples placed in beakers. At the end, the volume of water poured into samples was divided by the total volume of those samples.

Data Analysis: Soil pH, bulky density, soil moisture content, water holding capacity and porosity in sets with UREA, NPK fertilizers and control before and after growing maize were analysed using ANOVA. Means within groups were compared using Tukey-Kramer or Kruskal-Wallis test depending on their nature (parametric or non-parametric).

RESULTS AND DISCUSSION

The results of this study revealed that growing of maize with and without UREA and NPK fertilizers to end of vegetative stage is accompanied with changes in the studied soil properties. Before planting maize there were no differences in soil pH, bulk density, soil moisture content, water holding capacity and porosity in all the pots. Changes in soil pH, bulk density, soil moisture content, water holding capacity and porosity were observed in individual treatments after planting maize.

The results in Table 1 show the selected soil properties before and after planting maize to end of vegetative stage. In all three groups (with UREA, NPK and control) soil pH before and after growing maize had standard deviation of zero. However, in the control, soil pH was high (basic) before and after growing maize (above 8). This is contrary to Msanya *et al*. (2018) who reported soil pH of 7.5 in the region. Cultivation of maize without using inorganic fertilizers is probably associated with increase in soil pH. The increase in soil pH is not suitable for growing maize. Favourable condition for growing maize is slightly acidic (6.3) to neutral (7.4) (Sirisuntornlak *et al*., 2020). However, soil pH recorded in this study is in agreement with a study in Ethiopia (a dry region as well) (Alem *et al*., 2021). On the other hand, soil treated with NPK had the lowest soil pH, which is suitable for growing maize. Reduction of soil pH after treatment with inorganic fertilizer was also reported in China (Zhang *et al*., 2008) and Korea (Han, 2016). The increase in soil pH followed the order; control > UREA > NPK.

The bulk density of soil treated with NPK and the control decreased significantly after growing maize (t = 105.99, df = 10 and $p < 0.0001$), (t = 58.752, df = 10, $p < 0.0001$), respectively. On the other hand, in UREA treated soil the bulk density did not show any significant variation after growing maize. Soil treated with NPK ranked the least in bulk density; but with the highest porosity. The order of increasing soil porosity was; NPK > control > UREA. This finding is in agreement with Whalley (1995) who reported that soil bulk density was inversely related to soil porosity. On the contrary, this finding contradicts to Muhsin (2018) who reported about low soil porosity in NPK treated soil and NPK – free soil in Iraq. The discrepancy could be associated with differences in some other soil properties such as textural classes in the two regions. The increasing order of soil bulk density was; UREA > Control > NPK. Tukey Kramer Multiple Comparison test indicated that the differences in bulk density were between UREA and NPK, UREA and control and, NPK and control ($p < 0.001$ in all). High bulk density suggests more compaction of the soil which is likely to hinder nutrient availability. This is an indication that application of UREA affects availability of soil nutrients for the plants. Bulk density which is known to increase with soil depth is associated with soil compaction and causes hardness of the soil (Ramadhan, 2021). Additionally, bulk density is reported to negatively influence root growth and extension (Watson and Kelsey, 2006). The finding of this study is also in agreement with Katkar *et al*. (2012) who reported high soil bulk density on application of inorganic fertilizers. Based on the present study findings application of NPK may be recommended for promoting low bulk density (low soil compaction); however the same fertilizer did not perform well in enhancement of soil moisture content (it ranked the least). Reduction in soil moisture may result in a high compacted soil which can hinder water absorption in the deep layers of soil (Andrew *et al*., 2011). Extensive and deep root distribution is required for optimal yield of maize (Wei *et al*., 2009). Soil ease with extension of roots due to high porosity is crucial for enhanced nutrient uptake by plant roots (Wang *et al*., 2015). This finding is in agreement with Tesfahunegn (2019) who reported low soil moisture content after inorganic fertilizer application in Ethiopia.

Table 1: Caption on selected soil properties under fertilizer application (UREA/NPK) and fertilizer-free in growing maize plant to end of vegetative stage at the University of Dodoma

Treatment	Pot .no.	Soil parameters	Performance	
			Before growing maize (average)	After growing maize (average)
UREA	1	Soil pH	8.48	8.3
		Bulk density	1.4	1.41
		Soil moisture content	15.82	11.38
		Water holding capacity	0.27	1.13
		Porosity	38.31	45.35
	2	Soil pH	8.48	8.2
		Bulk density	1.39	1.41
		Soil moisture content	15.21	10.8
		Water holding capacity	0.27	1.11
		Porosity	38.92	45.35
	3	Soil pH	8.48	8.2
		Bulk density	1.38	1.4
		Soil moisture content	15.09	12.61
		Water holding capacity	0.26	1.28
		Porosity	34.82	45.95
	4	Soil pH	8.48	8.3
		Bulk density	1.41	1.41
		Soil moisture content	15.21	10.99
		Water holding capacity	0.3	1.08
		Porosity	39.12	45.35
	5	Soil pH	8.48	8.1
		Bulk density	1.37	1.39
		Soil moisture content	14.96	10.04
		Water holding capacity	0.28	1.13
		Porosity	41.21	46.12
	6	Soil pH	8.48	8.2
		Bulk density	1.39	1.4
		Soil moisture content	15.23	9.35
		Water holding capacity	0.26	1.02
		Porosity	38.29	45.74
NPK	7	Soil pH	8.48	7.5
		Bulk density	1.38	0.04
		Soil moisture content	16.01	2.76
		Water holding capacity	0.3	0.97
		Porosity	38.92	98.37
	8	Soil pH	8.48	7.5
		Bulk density	1.4	0.04
		Soil moisture content	15.22	2.9
		Water holding capacity	0.27	1.11
		Porosity	39.1	98.39
	9	Soil pH	8.48	6.9
		Bulk density	1.34	0.02
		Soil moisture content	15.22	1.21
		Water holding capacity	0.29	0.9
		Porosity	39.32	98.79
	10	Soil pH	8.48	7.3
		Bulk density	1.38	0.03
		Soil moisture content	15.29	2.21
		Water holding capacity	0.27	0.93
		Porosity	38.55	97.96
	11	Soil pH	8.48	7.1
		Bulk density	1.39	0.05
		Soil moisture content	15.05	3.83
		Water holding capacity	0.27	1.12
		Porosity	42.01	98.39
	12	Soil pH	8.48	7.5
		Bulk density	1.43	0.04
		Soil moisture content	14.85	3.11
		Water holding capacity	0.26	1.62
		Porosity	40.1	90.76
Control (no fertilizer)	13	Soil pH	8.48	8.8
		Bulk density	1.41	0.2
		Soil moisture content	13.49	16.78
		Water holding capacity	0.27	1.54
		Porosity	39.11	91.53
	14	Soil pH	8.48	8.6
		Bulk density	1.38	0.24
		Soil moisture content	16.04	20.85
		Water holding capacity	0.3	1.8
		Porosity	38.29	89.92
	15	Soil pH	8.48	8.8
		Bulk density	1.38	0.17
		Soil moisture content	15.22	14.07
		Water holding capacity	0.29	1.47

	Porosity	38.55	92.89
16	Soil pH	8.48	8.8
	Bulk density	1.42	0.16
	Soil moisture content	15.22	12.61
	Water holding capacity	0.26	1.36
	Porosity	38.88	93.24
17	Soil pH	8.48	8.7
	Bulk density	1.38	0.24
	Soil moisture content	15.37	20.8
	Water holding capacity	0.26	1.78
	Porosity	38.93	89.91
18	Soil pH	8.48	8.6
	Bulk density	1.32	0.22
	Soil moisture content	15.52	18.02
	Water holding capacity	0.27	1.62
	Porosity	38.31	90.76

†Bulk density (g cm^{-3}), Soil moisture content (%), Porosity (%)

The decrease in soil moisture content (%) in soil treated with NPK and UREA before and after growing maize plant was significant (t = 31.770, df = 10, $p < 0.0001$; U statistic = 0.000, U' = 36, $p = 0.02$), respectively.

The trend of increasing soil moisture content was; control > UREA > NPK ($p < 0.001$ in all). Tukey-Kramer test revealed that the differences in soil moisture content were between UREA and control and, NPK and control ($p < 0.01$). On the other hand, there was no significant variation in soil moisture content in the control before and after growing maize. Water holding capacity of soil treated with UREA, the control and NPK before and after growing maize increased significantly, respectively (t = 23.779, df = 10, $p < 0.0001$); (t = 18.58, df = 10, $p < 0.0001$); (U statistic = 0.000, U' = 36.000, $p = 0.0022$). The soil treated with UREA ranked the least in water holding capacity and porosity after growing maize. This suggests that application of UREA interferes with water and nutrient movements in the soil. The trend of increasing water holding capacity of the soil was; control > NPK > UREA. This finding is in agreement with Muhsin (2018) who reported low soil water holding capacity in Iran on application of NPK. The highest soil moisture content and water holding capacity was observed in the control (soil which was not treated with any inorganic fertilizer). This indicates that the use of inorganic fertilizers has negative effects on ability of soil to hold water.

Conclusion: This study investigated the impact of inorganic fertilizers (NPK and UREA) on the selected soil properties. The study revealed that application of NPK to the soil increases porosity but also lowering bulk density, soil moisture content and soil pH. The use of UREA increases soil bulk density but lowering the porosity and water holding capacity. The control soil (no inorganic fertilizers) increased soil pH, soil moisture content and water holding capacity. Reformulation of inorganic fertilizers is recommended due to water shortage in this era of changing climatic conditions.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability: Data are available upon request from the first author or second author.

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