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Full Length Research Paper

The basaltic soils of Plateau State, Nigeria: Properties, classification and management practices

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Characterization of soils is helpful in the appraisal of soil productivity. The study investigated detailed physico-chemical characterize of the soils developed on basaltic parent materials on the Jos plateau, Nigeria. The aim was to assess appropriate management practice for their sustainability in agricultural production. Four profiles pits were dug and studied, soil samples collected from pedogenetic horizons were analysed for particle size distribution, pH, fertility related properties. Results indicated that the soils were deep, clayey and reddish in colour (2.5YR 3/3-5YR 3/4). In terms of chemical characteristic, the soils are acidic (pH ranged between 4.6 and 5.6) with low to high CEC values (between 4.3 and 14.8 cmol (+) kg^{-1}) and generally low in organic matter on the average (<1.5%) and exchangeable bases. The four profiles developed on basaltic parent materials on the Jos Plateau of Nigeria were characterized and classified as Typic Haplustusts and Andic Haplustepts. All the soils were well drained in spite of high percent clay above 40% and silt fraction of 20 to 30%, which is apparently kaolinitic, with moderate to high aluminium saturation. Higher agricultural productivity of these soils is constraint by low nutrient-holding capacities and strong acidity. Ways to ameliorate these problems include; to raise the exchangeable Al^{3+} above toxicity and to supply Ca and Mg contents besides improving soil physical conditions.

Key words: Basaltic, typic haplustusts, andic haplustepts, kaolinitic, aluminium toxicity.

INTRODUCTION

Soil properties vary in spatial and temporal directions (Sokouti and Mahdian, 2011) and such variation depicts systematic changes as a functions of the geology and derived landforms (Burke, 2002), soil parent materials (Koojman et al., 2005) and soil management practices (landuse) (Amusan et al., 2006). Accordingly, Markus et al. (2008) reported that soil derived from basaltic rocks under tropical and sub-tropical environments are reported to contain kaolinite and sesquioxides as the major clay constituents and are variously classified as Oxisols, Ultisols and Alfisols (Soil Taxonomy) Jos Plateau covers an area of about 8600 km^2 in the central part of Nigeria with varying parent rocks. These parent rocks include basaltic, biotite-granites, alluvium, unconsolidated

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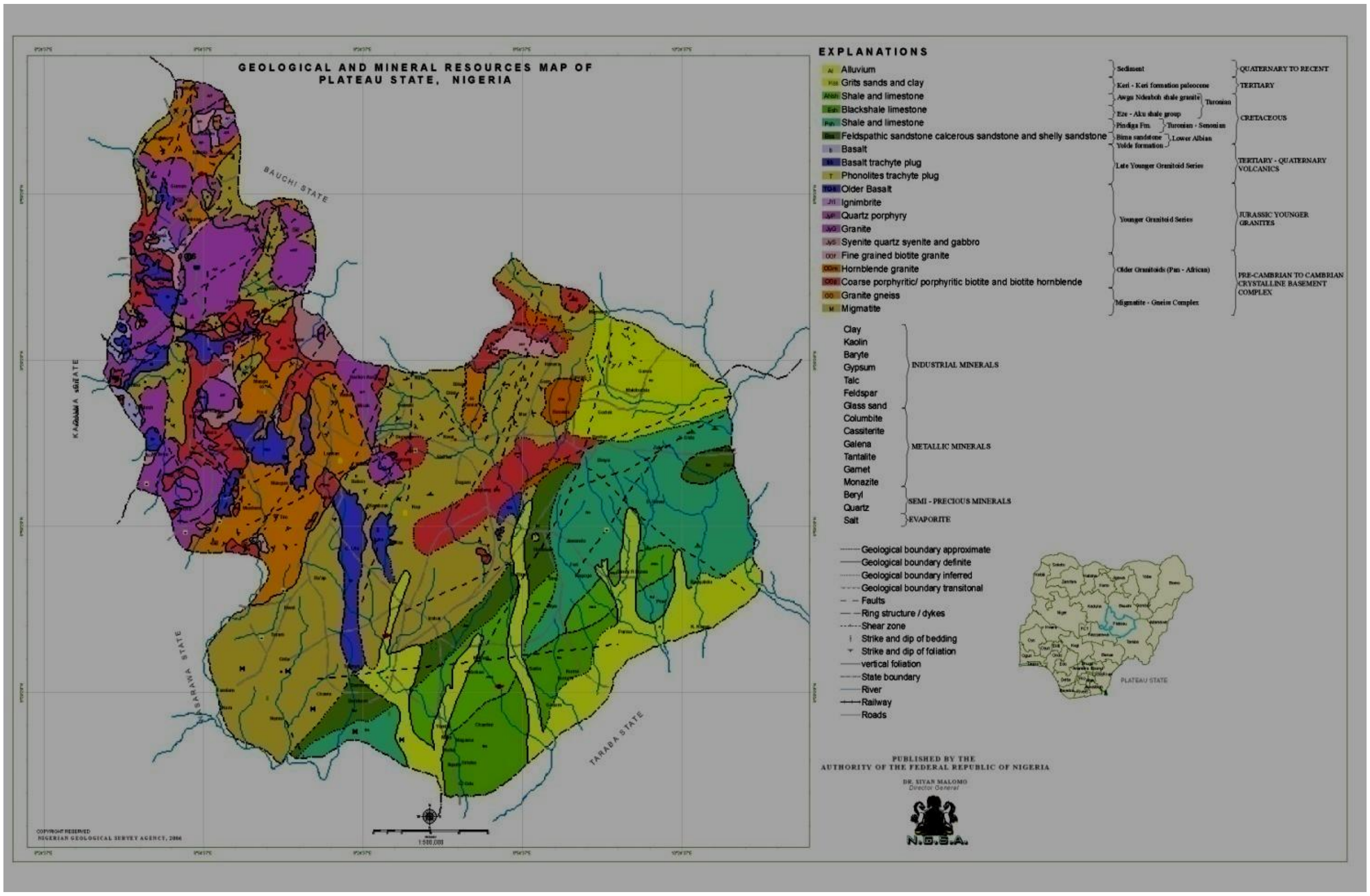

Figure 1. Geological and mineral resources map of Plateau State.

the central part of Nigeria with varying parent rocks. These parent rocks include basaltic, biotite-granites, alluvium, unconsolidated quaternary deposits and granite-gneiss on the Plateau (Olowolafe, 2002). The reddish basaltic soils are the major agricultural activities of thousands of smallholders in the Jos Plateau highland characterized by sub-humid tropical climate. These soils have developed from basaltic rocks and they occur over a wide range of altitudes 1600 to 3000 m above sea level (Olowolafe, 2002).

The productivity of these soils appears to have declined drastically following intensified land-use with poor management. This situation called for investigation that would provide a proper assessment and lead to formation of better management practices to increase yields on these soils. However, detailed information on their properties useful for management practices is lacking. The objective of this study were to investigate more detailed physico-chemical characterization of the soils developed on basaltic parent material on the Jos Plateau and classified them and subsequently recommend appropriate management practices for their sustained and continuous utilization in order to prevent their degradation.

MATERIALS AND METHODS

Description of study area

The study was carried out in the Jos Plateau, which forms a highland area standing above the surrounding plains in the central part of Nigeria. It lies between latitude 8° 30' and 10° 10'N and longitudes 8° 20' and 9° 30'E (Figure 1). Its boundary is marked for the most part by a steep fall to the surrounding plains, though it is more gradual in the east (Hill, 1978). Tropical wet and dry climate prevails in the area with long-term mean annual rainfall of 1300 mm (1008.6 to 2184.70) and mean annual temperature of about 22°C. The soil moisture regime is ustic while soil temperature regime is isohyperthermic (Eswaran et al., 1997). The area falls within the northern Guinea Savannah vegetation zone which is open woodland with tall grasses but the native vegetation has been considerably altered by human activities (Keay, 1953). The Jos Plateau geo-morphologically consists of gently undulating plains of low relative relief to hill ranges on the plains. It comprises of Precambrian Basement Complex rocks: gneisses, migmatites, granites and the Tertiary and Quaternary volcanic rocks: basalts, pumic etc. The survey areas which this paper report is a volcanic activity from Tertiary to recent times. They are distinguished as: Lateralized older basalts, unlateralized older basalts and newer basalts.

The study was conducted from November to March 2007-2008 only on those areas where basaltic soils were exposed already by erosion. A semi-detailed soil survey was carried out with the aid of aerial photo interpretation. Nine profile pits were dug in the basaltic parent material soils of the Jos Plateau but four modal representative profiles were reported. The pedons were described for their morphological properties which include soil colour, texture, structure, consistence, horizon boundary conditions and miscellaneous features such as cutans, roots, pores, etc. Following profile description, bulk and soil samples were collected from the genetic horizons for laboratory analyses.

Soil samples were air-dried in the laboratory, ground and sieved through 2 mm sieve, and the fine earth (< 2 mm) used for laboratory analyses. Particle size distribution was determined by the hydrometer method, using sodium hexametephosphate (Calgon) as the dispersant (Day, 1965). Measurement of soil pH was done in a 1:2.5 suspension in water and $CaCl_2$, the extraction of Ca, Mg, K and Na was made using 1N NH_4OAc (pH7) solution, Ca^{2+} and Mg^{2+} in solution were read on an atomic absorption spectrophotometer, while K^+ and Na^+ were read on the flame emission photometer. Cation exchange capacity was determined by the NH_4OAc saturation method. The CEC of the clay fraction was estimated from the equation of Sombrock and Zonneveld (1971) as follow:

$$\text{CEC (clay)} = \frac{\text{CEC (soil)} - 3.5 \times \%\text{OC} \times 100}{\%\text{Clay}}$$

Exchangeable acidity was extracted by 1 M KCl solution and determined by titration with standard NaOH solution. Organic carbon was determined by the dichromate wet oxidation method. Bulk density was determined gravimetrically using cores.

RESULTS AND DISCUSSION

The morphological characteristics of the soils developed on basalts parent material was presented in Table 1. Soil profiles BST01, BST02, BST03, and BST04 were generally very deep, that is greater than 150 cm depth. The Ap horizons of BST02 and BST04 are generally thin due to the high clay content of the soils, which complexes humus and thus reduces its ability to move downwards in the profiles. Accordingly, Kparmwang et al. (1998) opined that the thin Ap horizons might be partly due to cultivation which is usually on the flat, resulting in minimal deep mixing of the topsoil which is prone to moderate sheet erosion.

The surface horizons of soils were dominantly dark reddish brown as determined on moist state: 5YR 3/3; 5YR 3/4; 5YR 3/4; 5YR 3/3 in profiles BST01; BST02; BST03, and BST04 respectively. Profiles BST01 and BST02 have dark reddish brown (2.5YR 3/4) subsoils, while pedons BST03 and BST04 have a dark reddish brown (5YR 3/4; 5YR 3/4) subsoils. Similarly, the only difference in the surface and subsoils is the hue in pedons BST01 and BST02 and brightness of the subsoils of pedons BST03 and BST04. Oxidation-reduction of goethite coupled with leaching was suggested by Fanning and Fanning (1989) to give hues 5YR to 2.5YR in some soils formed under the tropical conditions. Presumably, hematite could cause the reddish colour in the subsoils. The darker colour of the Ap horizons is probably a result of melanization from humified organic matter, while the bright colour of pedons BST03 and BST04 are probably due to better drainage conditions in those pedons, thus allowing greater oxidation of iron thereby imparting the red colour to the soils (Table 1). The variation in soil colour among the soils was principally due to physiographic position of each pedon and differences in degree of profile development.

Soil horizon boundary conditions in basaltic soils were generally clear and smooth with the exception of BST03 and BST04. Though, the Ap horizons were quite distinct from the B horizons and marked by clear boundary due to melanization by organic matter in the Ap horizons. Thus, there is a greater degree of horizon differentiation in profiles BST01 and BST02 than BST03 and BST04, indicating a greater degree of soil development in BST02, but in pedon BST04 this is due to non-soil layers. The granitic soils posses' clear and smooth boundary differentiation in the surface horizons with irregular subsoils.

Particle size distribution data for the soils is presented in Table 2. The sand fraction in the surface horizon of soils developed on basaltic parent material had values ranging from 10 to 38% with a mean (26%). One striking feature of the sand fraction in the soil type is decrease with abrupt increase in the third horizons of the profiles except Profile BST03. The sand fraction in profile BST03 had near similar values with depth except for horizon 2BC1 that has increased (Table 2). The clay fraction was generally above 40%, giving a dominantly clay texture to the soils. The fraction ranged between 28 to 66% in the studied soils. The surface horizon ranged from 28 to 64% with a mean of 49%. The clay content was high in surface horizon with the exception of BST02 (28%) and increased with depth, nevertheless an irregular distribution pattern was observed in the study. The clay content shows marked increases in the Bt horizons of the profiles (Table 2), but it decreases with depth in profile BST03. Thus, the field evidence of clay translocation (cutans) from the surface horizons into Bt horizons of the pedons, strongly suggesting that the Bt horizons of this parent material is argillic/kandic horizons. Studies conducted on basaltic parent material revealed high clay contents with iron oxides as subsidiary weathering products (Singer, 1966; Ogunwale, 1985; Eshett, 1987; Markus et al., 2008).

The bulk density values for surface horizons in the basaltic soils ranged from 0.770 to 1.171 Mgm^{-3} with a (mean 0.992 Mgm^{-3}) Table 2. The bulk density decreased with depth, except profile BST01 that increased with depth which is irregular in distribution. Bulk density is <1.0 Mgm^{-3} in all horizons of profiles BST03 and BST04. The low bulk density, a requirement of, but not exclusive to andic properties, occurs in volcanic soils as a consequence of the development of a porous soil structure arising from the interaction of non-crystalline materials and soil organic matter content (Vacca et al., 2009).

Table 1. Summary of the morphological features of soil profiles**.

Horizon	Depth	Munsell colour		Mottle			Consistency				
	(cm)	Moist	Dry	Colour	Texture	Structure	Wet	moist	dry	Boundary	Miscellaneous observations
Basaltic parent materials											
Profile No: BST 01											
Ap	0-35	5YR 3/3	5YR 4/6	-	C	2msbk	SP	fi	sh	gs	Many fine-medium roots; common hard fine gravel, common fine tubular pores, few empty fine medium termite/ant holes.
Bw1	35-60	2.5YR ¾	2.5YR 4/6	-	C	2msbk	SSPS	fi	sh	cs	Few fine tubular pores; few medium-coarse roots; many fine hard Mn gravel; clay cutans along pores.
Bw2	60-88	2.5YR 3/6	2.5YR 4/6	-	CL	1fsbk	SP	fi	sh	cs	Few fine roots; few fine tubular pores; many medium-hard Fe/Mn concretions.
Bt1	88-130	2.5YR ¾	2.5YR 3/6	-	C	2msbk	SP	fi	sh	ds	Few fine-medium roots; irregular common medium hard Fe/Mn concretions; common fine tubular pores.
Bt2	130-178+	2.5YR ¾	2.5YR 3/6	-	C	2msbk	SSPS	fi	sh	-	Very few fine roots; common soft to slightly hard Fe/Mn concretions; common very fine pores.
Profile No: BST 02											
Ap	0-16	5YR ¾	-	-	CL	2msbk	SP	fi	S	cs	Many fine roots; many fine few-medium pores; few ant nests.
Bt1	16-70	2.5YR ¾	2.5YR 3/6	-	C	2msbk	SP	fi	H	cs	Many fine roots; many fine-medium pores; vertical cracks, many medium ant nests.
Bt2	70-117	10YR ¾	2.5YR 3/6	7.5R 4/8	C	2msbk	SP	fi	H	cs	Many fine roots; many fine pores; few fine Fe/Mn concretions.
BC	117-152	5YR ¾	-	-	C	2msbk	SSPS	fi	H	cs	Few fine roots; many medium-coarse Fe/Mn concretions; few medium weathered basaltic boulders.
C	152-175+	5YR ¾	2.5YR 3/6	-	C	2msbk	SP	fi	h	-	Few fine roots; many medium soft Fe/Mn concretions; many medium-coarse partially weathered basaltic parent materials.
Profile No: BST 03											
Ap	0-37	5YR ¾	-	-	C	1msbk	SSPO	Fi	S	gs	Many fine-medium pores; many fine-medium roots; common ant/termites nests.
Bw1	37-100	5YR ¾	-	-	C	2msbk	SP	Fi	H	cw	Many fine pores; few fine soft iron nodules.
2BC1	100-110		-	-	C	-	-	-	-	-	Partially weathered basaltic materials.
2BC2	110-143	5YR ¾	-	-	C	2msbk	SP	Fi	H	cs	Common medium pores.
2Cr	143-190	5YR ¾	-	-	C	2msbk	SP	Fi	H	-	Many coarse partially weathered basaltic materials.
Profile No: BST 04											
Ap	0-15	5YR 3/3	-	-	C	1fsbk	SPO	Vfr	S	cs	Many fine pores; many fine-medium roots; few termites/ant nests.

Table 1. Contd.

Bw1	15-110	5YR ¾	5YR 4/6	-	C	2csbk	SP	Fi	H	ds	Many fine-common pores; many fine roots; many medium Fe/Mn concretions; few termites' nests.
Bw2	110-156	5YR ¾	5YR 4/6	-	C	2msbk	SP	Fi	H	cg	Many fine pores; few medium-coarse Fe/Mn concretions; partially weathered basaltic boulder of medium-coarse size.

Table 2. Particle size distribution, bulk density and porosity of the pedons

Horizon	Depth (cm)	Sand (2000-50 μm)	Silt (50-2 μm)	Clay (<2 μm)	Bulk density Mgm^{-3}	Porosity $m^{-3}m^{-3}$	Textural class
				BST01 CHAHA			
Ap	0-35	30	20	50	1.049	0.396	Clay
Bw1	35-60	16	20	64	1.141	0.431	Clay
Bw2	60-88	44	22	34	1.304	0.492	Clayloam
Bt1	88-130	20	22	58	1.212	0.457	Clay
Bt2	130-170+	18	26	56	1.008	0.380	Clay
				BST02 NITA			
Ap	0-16	38	34	28	1.171	0.442	Clayloam
Bt1	16-70	12	22	66	1.010	0.381	Clay
Bt2	70-117	20	22	58	1.008	0.380	Clay
BC	117-152	26	26	48	1.010	0.381	Clay
C	152-175+	38	18	44			Clay
				BST03 RA-HOSS			
Ap	0-37	10	26	64	0.978	0.369	Clay
Bw1	37-100	14	26	60	0.945	0.357	Clay
2BC1	100-110	24	28	48			Clay
2BC2	110-143	14	24	62	0.544	0.205	Clay
2Cr	143-190	14	32	54	0.913	0.345	Clay
				BST04 TA-HOSS			
Ap	0-15	24	22	54	0.770	0.291	Clay
Bw1	15-110	20	22	58	0.602	0.227	Clay
Bw2	110-156	38	24	46	0.783	0.295	Clay
BC	156-190	38	26	36	0.641	0.242	Clayloam

Table 3. Soil chemical properties of the pedons.

Horizon	Depth	pH		Exch acidity		OC	Exchangeable bases Cmol(+)kg^{-1}					CEC	CEC (clay)	ECEC	Base Sat
	(cm)	(H_2O)	$CaCl_2$	$Al^+ + H^+$	H^+	%	Ca	Mg	K	Na	Σbases		Cmol(+)kg^{-1}		(%)
Basaltic parent material BST01															
Ap	0-35	5.3	4.9	2.3	1.0	0.54	0.90	0.026	0.266	0.045	1.237	12.2	20.62	3.537	10.0
Bw1	35-60	5.2	4.6	1.2	0.4	0.66	1.53	0.324	0.296	0.071	2.221	8.2	9.20	3.421	27.0
Bw2	60-88	4.6	4.2	2.2	0.8	0.68	1.26	0.501	0.197	0.039	1.997	4.3	5.35	4.197	46.0
Bt1	88-130	5.4	4.6	0.8	0.4	0.24	1.46	0.063	0.297	0.036	1.856	7.0	10.62	2.656	27.0
Bt2	130-170+	5.4	4.6	0.9	0.4	0.41	0.89	0.097	0.164	0.055	1.206	9.6	14.58	2.106	13.0
BST02 NITA															
Ap	0-16	5.0	4.5	1.3	0.3	0.68	1.57	0.247	0.230	0.030	2.077	14.2	42.21	5.377	15.0
Bt1	16-70	5.4	4.8	1.6	0.5	0.60	1.42	0.314	0.294	0.082	2.110	14.8	19.24	3.710	14.0
Bt2	70-117	5.6	4.5	2.8	0.5	0.39	1.53	0.339	0.114	0.050	2.033	12.6	19.37	4.833	16.0
BC	117-152	5.3	4.7	3.2	1.2	0.40	ND	0.195	0.228	0.066	0.489	10.2	18.33	3.689	05.0
C	152-175+	5.2	5.0	3.3	1.2	0.41	2.68	0.287	0.147	0.084	3.198	12.4	24.92	6.498	26.0
BST03 RA-HOSS															
Ap	0-37	5.2	4.6	2.1	0.6	1.08	1.47	0.002	0.049	0.042	1.563	11.6	12.22	3.663	14.0
Bw1	37-100	5.2	4.2	1.3	0.4	0.33	1.35	0.028	0.068	0.124	1.570	9.2	13.41	2.870	17.0
2BC1	100-110	4.6	4.2	1.1	0.2	0.55	1.50	0.028	0.188	0.077	1.793	9.8	16.41	2.893	18.0
2BC2	110-143	4.9	4.5	2.2	0.7	0.51	1.30	0.176	0.246	0.032	1.754	9.0	11.61	3.954	20.0
2Cr	143-190	5.0	4.6	3.8	1.5	0.42	4.83	0.029	0.278	0.062	5.199	18.7	31.91	8.999	28.0
BST04 TA-HOSS															
Ap	0-15	5.5	5.4	1.4	0.6	1.23	1.19	0.152	0.181	0.045	1.568	8.5	7.77	2.968	18.0
Bw1	15-110	5.3	5.0	1.3	0.4	0.43	1.60	0.026	0.242	0.046	1.914	9.2	13.27	3.214	21.0
Bw2	110-156	4.8	4.7	1.7	0.8	0.31	1.22	0.115	ND	0.071	1.406	8.2	15.47	3.106	17.0
BC	156-190	5.6	5.2	1.2	0.2	0.41	1.48	0.152	0.027	0.102	1.761	5.0	9.90	2.961	15.0

Nutrient status of the soils

Generally the soils are acidic (pH values mostly < 5.5) (Table 2). Lower values were reported by Eshett (1987) on basaltic soils at Ikom in the humid forest zone (range 4.6 to 5.2) and on basaltic soils on the sub-humid Jos Plateau (range 4.2 to 5.5). The pH values increase slightly down the profiles, in consonance with the less leached conditions of the area. Exchangeable bases contents of the soils are low to very low. Olowolafe (1995) reported similar results on the Jos Plateau soils; he urged that the silicate clay mineral in the Inceptisols, Alfisols and Ultisols was kaolinite. As pointed out earlier, annual rainfall was about 1260 mm. leaching of basic cations by rainfall and the low pH values of the soils are among the factors that favour kaolinite formation. The dominance of low activity clay minerals has undoubtedly contributed to their low to very low CEC (Table 3). Certainly these have pronounced influences on the productivity of the soils.

The exchangeable acidity for the soils ranged from 0.8 to 3.3 cmol (+) kg^{-1} (mean 1.763). Indeed, the Ap horizons had highest values across the profiles (Table 3). This result is similar with the low exchangeable bases and high exchangeable acidity of Eshett (1987) for the Ikom soils and Markus et al. (2008) for Kuantan series. Buol et al., 1980) reported that exchangeable

(Al is generally low in basaltic soils. It is therefore possible that the high exchangeable Al obtained is a result of excessive weathering that might have led to the subsequent release of structural Al from clay minerals. Aluminium toxicity might be a problem to crop production in the study area. The percentage aluminium saturation was above 30% critical level (Fageria et al., 1988).

The organic carbon (OC) contents of the soils decreased with increase in depth in all the pedons. The surface soil values were generally rated low with the exception of profiles BST03 and BST04 that have moderate values (>1.0%). This is in conformity with the findings of Yaro et al. (2006). The low in OC content is attributed to paucity in vegetation, low return of crop residues and mineralization in the region.

Soil classification

The diagnostic criteria for classification according to the USDA Soil Taxonomy (Soil Survey Staff, 2003) include an ustic soil moisture regime due to a pronounced dry season lasting between 5 to 6 months and an isohyperthermic soil temperature regime characteristic of the tropics. Pedons BST01 and BST02 are characterised by ochric epipedons and argillic/kandic B horizons, whilst pedons BST03 and BST04 have cambic B horizons. Base saturation (NH_4OAc) is low, generally lower than 50% (Tables 2 and 3). The clay mineralogy of the soils was dominated by kaolinite, oxides of Fe and Al with traces of 2:1 minerals (Hassan, 2010). Ogunwale (1985) also found kaolinite as the dominant clay minerals on the basaltic soils of the Jos Plateau.

Pedons BST01 and BST02 are therefore classified at the family level of Soil Taxonomy as Typic Haplustults, fine clayey, vermiculitic, isohyperthermic, while pedon BST03 as Andic Haplustepts, very fine clayey, kaolinitic, isohyperthermic and BST04 qualifies as Andic Haplustepts, fine clayey kaolinitic, isohyperthermic.

According to the World Reference Base for Soil Resources (2006), pedons BST01 and BST02 qualified to be Ferralic Acrisols. These are soils with argic B horizons which had CEC of clay fractions less than 24 cmol (+) kg^{-1} clay and base saturation (by NH_4OAc) of less than 50% in at least, part of the B horizons within 125 cm of the surface. Pedons BST03 and BST04 were classified as Cambisols because they have weakly developed soils with a B horizon (cambic horizon). At the second level, BST03 and BST04 were placed on Andic due to andic horizon within 100 cm from the soil surface. The clay mineralogy revealed short-range-order minerals; allophone and imogihite (Hassan, 2010).

Management options

Generally, the particle sizes in basaltic soils are dominantly clay fraction with values above 40% and with low sand content. Low bulk density was evidence in soils with some profiles (BST03 and BST04) <1.0 Mgm^{-3}. Thus, consequence of the development of a porous soil structure arising from the interaction of non-crystalline materials and soil organic matter. However, the soils were found to be very strongly to moderately acid in the Ap horizons with inconsistence vertical variation down the profiles. Exchangeable Al^{3+} constituted the larger proportion of exchangeable acidity, especially in the surface horizons. Thus, aluminium saturation >20% is commonly regarded as a potential Al toxicity in sensitive crops.

Similarly, low OC and exchangeable bases observed in the soils constitute to decline in crop productivity as was reported by earlier researchers. In the same vein, the soils possesses excellent physical condition (friable and highly porous) although they are plastic and sticky when wet as, it is usual for clayey soils. The ability to supply nutrients can be improved in soils containing amorphous materials through the addition of organic matter. Since OM has a large CEC under most soil conditions, addition of OM enhances the CEC of the soil. The sticky nature of the soil when wet, farmers are advice to use knife to scoop the sticky blades. Further, experimentally determined rate of slow reacting liming materials can neutralize the acidity, that is, to raise the exchangeable Al^{3+} above toxicity and as well as supply Ca^{2+} and Mg^{2+} as nutrients besides improving soil physical conditions.

Conclusion

Soils developed on basaltic parent materials on the Jos Plateau, Nigeria are intensely leached and have acidity problems. The soils are inherently low in soil fertility related properties (Hassan, 2010) and exchangeable bases. With the present low-input agriculture in the area, nutrient depletion will certainly continue, a situation which can lead to total loss of crop productivity and degradability of the soil quality and/or environment.

Sustainable crop production calls for improved management practices that will effectively minimize erosion and also enhance and maintain soil quality and productivity. Incorporation of crop residues, animal wastes and full recommended rate of N and P from inorganic fertilizer may be advantageous for boosting the fertility of the soils. Further, experimentally determined rate of slow reacting liming materials can neutralize the acidity, that is, to raise the exchangeable Al^{3+} above toxicity and as well as supply Ca^{2+} and Mg^{2+} as nutrients besides improving soil physical conditions.

Conflict of Interest

The authors have not declared any conflict of interest.

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Inoculation, phosphorous and zinc fertilization effects on nodulation, yield and nutrient uptake of Faba bean (*Vicia faba* L.) grown on calcaric cambisol of semiarid Ethiopia

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A field experiment was conducted in 2010 crop season with three factors: Inoculation (U = no inoculums and I = with inoculums), three levels of P (0, 20, 40kgPha^{-1}) and three levels of Zn (0, 15, 25kgZnha^{-1}) fertilizations. The experiments were laid in randomized complete blocks in three replications on calcaric cambisols to study effects of inoculation, P and Zn fertilizations on nodulation, yield, yield components, and the uptake N, P and Zn by the plant. Composite soil samples were collected one month before sowing and plant samples were taken both at 50% flowering and plant maturity. Findings showed that, the main and interaction effects of inoculation, P and Zn fertilization were found to affect significantly ($P < 0.05$) the root distribution and mass of nodules, the concentration of N, P and Zn in nodule, root and leaf tissues at 50% flowering, At maturity, P and Zn were found to significantly increase the root length, root fresh weight of the plant, and inoculation significantly affected the root fresh weight. Phosphorous and Zn fertilization improved the grain yield, pods plant^{-1}, grain pod^{-1}, number of branches, and the grain uptake of N, P and Zn nutrients. The combined application of inoculation, P and Zn fertilization increased the grain yield on average by 1.3 Mg ha^{-1}. Phosphorous and Zn fertilization alone increased the grain P and Zn uptake by 1.1 and 2.7 × 10^{-2} kg ha^{-1}, respectively, and the combined application of inoculation, P and Zn improved the N uptake of the faba bean grains on average by 40 kg ha^{-1}. Thus, inoculating the legume with efficient and compatible rhizobium, and fertilizing it with P and Zn should be recommended to soils deficient in P and Zn, especially in alkaline calcareous soils.

Key words: Semiarid, nodulation, inoculation, zinc, phosphorus, yield, nutrient uptake, faba bean.

INTRODUCTION

Ethiopia is one of the largest faba bean (*Vacia faba* L.) producing country in Africa and the world (Hawitin and Hebblewaite, 1993). Faba bean is a cool-season food legume (CSFL), grown in Ethiopian highlands and occupies about 34% of the total cultivated land under pulses (CSA, 2012). The grain of faba bean is an

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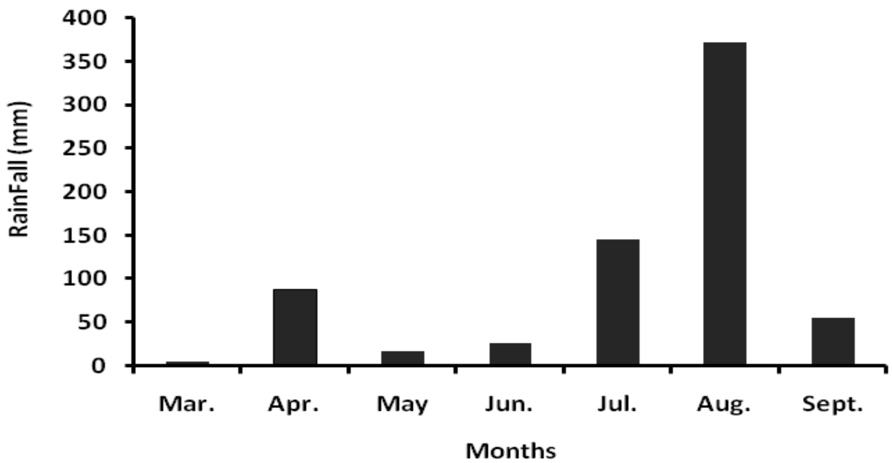

Figure 1. Monthly rainfall (mm) distribution for 2010 at MU.

important source of proteins and its straw serves as animal feed and soil fertility restorer. In addition to being an important food crop, faba bean also plays an important role in legume-cereal cropping system because of its high N_2 fixing ability. Furthermore, grain legumes, such as faba bean could serve as alternative to fallow and in turn increase land use, weed control and reduce the need for inorganic fertilizers (Carlos and Minguez, 2001).

The yield of faba bean is low, mainly limited by mineral nutrient availability and lack of efficient and compatible strains of rhizobium in the soil (Habtegebrial et al., 2007). However, faba bean, among the grain legumes is reported to derive the highest percentage of N from the atmosphere (Hardarson et al., 1987), and the yield, protein content, nodulation and amount of N_2 fixed are reported to increase with rhizobium inoculation and mineral nutrient applications (Elsiddig and Abudlhafize, 1997; Shibru and Mitiku, 2000; Habtegebrial et al., 2007). Therefore, accumulation of enough N by the legume and the subsequent yield effects depend on the number, efficiency and compatibility of rhizobia and nutrient constraints that affect nodulation and N-fixation (Aynabeba et al., 2001).

Phosphorous and Zinc are the major yield limiting nutrients in the highlands of Ethiopia (Bereket et al., 2011), and their effect is severe in alkaline calcareous soils, where P is fixed in apatite Ca minerals and Zn is precipitated as insoluble oxides and hydroxides, and adsorbed strongly to carbonate mineral surfaces (Alloway, 2004). Phosphorous and Zn are important mineral nutrients to the growth and biological N_2 fixation (BNF) of legumes, and the requirement of P and Zn by faba bean is relatively high, which is in the range of 20 to 30 kg P ha^{-1} and 10 to 25 kg Zn ha^{-1} (Prasad and Power, 1997; FAO, 2000). Phosphorous is needed in relatively large amount by legumes and in addition to promoting the host legume growth; it has specific roles on N_2 fixation and nodule initiation, growth and development (Leidi and Rodiguez-Navarro, 2000). Zinc is also an important micronutrient for BNF and likely involved in leghaemoglobin synthesis. Deficiency of Zn in legumes is found to reduce the number and size of nodules (Marsh and Waters, 1985). The other important aspect of P and Zn nutrition is the interaction effect between them, especially in soils marginally deficient in both nutrients, where a positive interaction is reported when fertilized together in these soils (Havlin et al., 2005).

Few studies on the effect of inoculation and P fertilization on the yield, nodulation and N_2 fixation of legumes exist (Shibru and Mitiku, 2000; Amanuel et al., 2000; Habtegebrial and Singh, 2006), but studies on the combined effect of inoculation, P and Zn fertilization to grain legumes, grown on alkaline calcareous soils are generally scarce. Prior to this study, Weldu et al. (2012) was conducted a greenhouse pot experiment in 2009 to determine the effect of P and Zn fertilization on the response of faba bean. The current study, in continuation of the greenhouse experiment, intended to further evaluate at field level the effects of inoculums with P and Zn fertilization on yield, yield components, nodulation and nutrient uptake of faba bean on soils deficient in P and Zn under rainfed conditions.

MATERIALS AND METHODS

Site description

The experiment was conducted at Mekelle University (MU) Campus, Tigray-northern Ethiopia at 13°14'N and 39°32'E, and at 2100 m.a.s.l in the 2010 crop season. The site is located in a semi-arid agroecological zone with annual rainfall, ranging between 200 and 700 mm. The rainfall distribution is bimodal with short rain season (March-April) and main rain season (June-September) (Figure 1). The pattern, however, is extremely variable with high probability of no rain during the short rain season. The annual rainfall at Mekelle for the 2010 crop season was 711 mm. The average minimum and maximum temperature for the same season (June to October) were 11.8 and 24.3°C respectively. The soil type of the study site is Cambisol (UNESCO, 1994). The surface of the soil (0-0.2 m) is clay-loam in texture and contains 40% clay, 32% silt and 28% sand.

The soil had a pH of 7.7, electrical conductivity of 2.1 dS m^{-1} and CEC of 37 $cmol_c$ kg^{-1}. It contained 27% of $CaCO_3$, 1.42% soil organic matter, 0.14% total N, 5.5 mg kg^{-1} available-P, 0.48 mg kg^{-1} DTPA extractable-Zn, and 188 mg kg^{-1} extractable-K.

Experimental design and treatments

The experiment was laid out in randomized complete block design with three replications. A factorial combination of three factors: P with three levels (0, 20, kg P ha^{-1}), Zn with three levels (0, 15, 25 kg Zn ha^{-1}) and inoculation with two levels (U = no inoculums and I= with inoculums) were applied in 6.3 m^2 (2.1 m × 3 m) plots. Triple super phosphate (TSP) and zinc oxide (ZnO) were used as the source of P and Zn treatments. 23 kg N ha^{-1} and 40 kg K ha^{-1} in the form of urea (46% N) and Potassium chloride (52.5% K) respectively, were used as starter-N and basal dressing. The mixture of the treatment elements, the starter-N and basal-K were banded 5 cm to the side and 3 cm below the seeds at sowing.

The faba bean seeds (*Vicia faba* cv. CS20DK) were obtained from the Ethiopian Seed Agency (ESA). The inoculant used was *Rhizobium leguminosarum* biovar *vacia* strain EAL-110, obtained from the National Soil Research Laboratories (Addis Ababa, Ethiopia). The legume seeds were inoculated at the time of sowing with a powder containing an equivalent of 10^8 viable bacteria cells g^{-1}.

Prior to inoculation, the seeds were surface sterilized as follows: Washed with 70% (v/v) ethanol for 5 min, rinsed twice with sterilized water, shaken by hand for 15 min in 30% (v/v) H_2O_2, and rinsed four times with sterilized water. The surface unharmed faba bean seeds were then soaked overnight in distilled water and made ready for inoculation and sowing the next morning. The legume seeds were sown by hand with spacing between plants and rows of 7 and 30 cm respectively, as recommended by ESA in the 20th of July, 2010. Thinning of the faba bean seedlings was carried out to make the final plant density to 50 plants m^{-2}. Hand weeding of faba bean plots was carried out three times before pod filling.

Soil sampling and analysis

Composite soil samples from 0 to 20 cm depths were collected one month before sowing. Soil samples after drying and sieving were analyzed for pH (1:2.5 soil: water ratio), and EC_e of the saturated paste extract. Cation exchange capacity (CEC) was determined by the ammonium acetate method and the calcium carbonate content of the soil was determined by the method outlined in Sahlemedhin and Taye (2000). Soil organic carbon (SOC) was analyzed by Walkley and Black method (Nelson and Sommers, 1982). Total soil N (TN) was determined as total kjeldahal N (Bremer and Mulvaney, 1982), available-P was extracted using 0.5 M $NaHCO_3$ at pH 8.5 and determined as described in Olsen and Sommers (1982), and extractable K was analyzed as given in Knudsen et al. (1982). Available Zn was extracted using the diethylene triamine penta acetic acid (DTPA) chelate complex and determined using the method developed by Lindsay and Novell (1978).

Plant sampling and analysis

Nodulation was assessed at 50% flowering stage of the plants. Ten randomly selected plants from each plot were uprooted. Soil adhering to the roots was removed by washing with tap water. Nodules from the crown and lateral root portions were removed separately and spread on a sieve for some minutes until the water had drained from the surface of the nodules. The crown region was defined as that part of the root extending 3 cm in all directions from the stem base, whereas the lateral roots were those parts of the root system extending beyond 3 cm from the stem base (CIAT, 1988). The total number of nodules, number of nodules in the crown and lateral portion of the root, fresh weight and volume of the nodules were recorded.

Measurements on the length and fresh weight of roots were obtained from the plants obtained at 50% flowering. Newest top matured leaves and roots were collected from ten faba bean plants for nutrient analysis. At maturity, grain samples were collected from each plot for similar nutrient analyses. All the plant samples were then oven dried at 70°C for 48 h. The samples were ground to pass through a 1-mm sieve and the N, P and Zn content of these plant tissues were determined from their dry ash and wet digested samples (Sahlemedhin and Taye, 2000).

At physiological maturity, plants harvested from 1-m^2 inner row areas of each plot were used to record yield and yield components. Grain yield and number of pods m^{-2} were obtained by collecting all pods from these plants. The number of seeds pod^{-1} was then counted from 20 randomly picked pods. Number of branches $plant^{-1}$ and plant height was determined from the 10 randomly picked plants of each plot.

Statistical analysis

Field data were analyzed using SAS (version 9.1) (SAS Institute, 2003). Three-factor analysis of variance was performed to evaluate the main and interaction effect of inoculation, P and Zn fertilization on yield, yield components, nodulation, and nutrient uptake. LSD was used to compare treatment means and the probability significance level of a treatment effects and correlations were evaluated at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Nodulation and root growth

During the assessment, the nodule color across all inoculated treatments was invariably pink, indicating rhizobium infection of the roots.

Inoculation, P and Zn fertilization have significantly affected the distribution and total number of nodules, their dry mass and volume; although inoculation only affected the root crown nodules and not the lateral and total number of nodules (Table 1). In this experiment, P and Zn were found to significantly increase the root length of faba bean plant and its fresh weight, while inoculation only affected the root fresh weight and not its length (Table 1). Strong and positive two-way interactions between inoculation, P and Zn were also observed, affecting significantly the same parameters, shown in Table 1.

Inoculation, P and Zn treatments alone increased the average dry mass of nodules by 83, 109, and 13%, respectively. In turn, the combined effect of inoculation, P and Zn fertilization increased the average number and mass of nodules by 34 and 0.34g, compared to the control, corresponding to 53 and 151% increase.

Table 1. Distribution, total number, dry weight (g) and volume (cm^3) of nodules, and root growth at 50% flowering of the faba bean plant.

Treatment	Number of nodule plant^{-1}			Nodule dry wt.	Nodule volume	Root length	Root fresh
	Crown	Lateral	Total	(g plant^{-1})	(cm^3plant^{-1})	(cm)	wt. (g)
UP_0Zn_0	42.2	22.1	64.3	0.21	0.21	10.3	14.4
IP_0Zn_0	58.5	30.7	89.2	0.36	0.34	11.5	16.0
UP_0Zn_1	56.3	29.5	85.8	0.22	0.22	13.8	17.7
IP_0Zn_1	63.7	33.4	97.1	0.37	0.36	13.9	19.7
UP_0Zn_2	64.4	33.7	98.1	0.23	0.22	12.7	19.0
IP_0Zn_2	66.7	28.8	95.5	0.38	0.37	11.3	21.1
UP_1Zn_0	59.3	31.8	91.1	0.38	0.37	16.3	16.9
IP_1Zn_0	65.9	31.1	97.0	0.53	0.49	12.4	18.7
UP_1Zn_1	67.4	34.5	101.9	0.39	0.38	13.8	18.9
IP_1Zn_1	68.9	35.5	104.4	0.66	0.58	13.1	21.0
UP_1Zn_2	68.1	36.1	104.2	0.45	0.43	11.4	19.4
IP_1Zn_2	62.2	35.7	97.9	0.77	0.68	11.9	22.0
UP_2Zn_0	65.2	32.6	97.8	0.45	0.44	18.7	17.8
IP_2Zn_0	68.2	34.2	102.4	0.89	0.77	18.8	19.8
UP_2Zn_1	70.4	35.7	106.1	0.41	0.39	14.6	19.2
IP_2Zn_1	71.9	36.9	108.8	0.79	0.72	15.4	21.3
UP_2Zn_2	63.0	37.6	100.6	0.51	0.48	10.9	19.8
IP_2Zn_2	65.2	33.0	98.2	1.16	0.98	14.5	21.6
LSD_I	2.44	ns	ns	0.034	0.031	ns	0.81
LSD_P	2.99	2.90	5.64	0.041	0.037	1.07	0.99
LSD_{Zn}	2.99	2.90	5.64	0.041	0.037	1.07	0.99
R^2	0.77	0.51	0.67	0.96	0.95	0.97	0.98

ns = Not significant at P = 0.05, U= uninoculated, I= inoculated; P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}; Zn_0 = 0 kg Zn ha^{-1}, Zn_1 = 15 kg Zn ha^{-1}, and Zn_2 = 25 kg Zn ha^{-1}.

Interaction plots indicate that the highest nodule mass was obtained when the plant was fertilized with P_2 and Zn_2.

Inoculating grain legumes with efficient strains of rhizobium is widely reported to increase the number, mass and volume of nodules (Shibru and Mitiku, 2000; Nuruzzaman et al., 2005), and the corresponding grain and total dry matter yield of faba bean. However, nodule mass is reported to be more reliable measure of nodulation than nodule number, which is also found to strongly correlate with the total amount of N_2 fixed and dry matter accumulation (Fawz et al., 2002). The nodules most affected by inoculation were found to be those in the faba bean root crown, as similarly found by Amanuel et al. (2000). The crown nodules are the first to be formed and more likely to originate from the inoculated strains (CIAT, 1988).

Phosphorous is involved in nodule metabolism, stimulating their growth and development (Leidi and Rodiguez-Navarro, 2000; Giller, 2001). Adequate fertilization of Zn was found to increase the number and size of nodules, as it might be possibly involved in the synthesis of leghaemoglobin (Marsh and Waters, 1985), while addition of sufficient P and Zn nutrients were associated with the increase of root growth and development (Havlin et al., 2005; Fageria, 2009).

Nutrient concentrations in the plant tissues

Main effects of inoculation, P and Zn fertilization, and their interactions have significantly ($P < 0.05$) affected the concentration of N, P and Zn in nodule, leaf and root tissues of the faba bean plant (Table 2).

Combined effects of inoculation, P and Zn fertilization increased the N concentration of the nodule, leaf and root tissues by 0.4, 2.7 and 0.6%, respectively, compared to the control. Phosphorous fertilization improved the P content of the nodule, leaf and root by 0.04, 0.06 and 0.16%, and Zn fertilization increased the Zn concentration of the nodule and leaf by 0.76 and 31 mg kg^{-1}.

The increase in the concentration of N and P in nodules, roots and shoots of faba bean and other grain legume with inoculation and P fertilization was similarly reported by many authors (Nuruzzaman et al., 2005; Yamane and Skjelvåg, 2003; and Habtegebrial and Singh, 2006). Increasing the supply of P to legume plants, such as pea and faba bean was found to considerably increase the concentration N and P in their

Table 2. The N, P and Zn contents of the nodule, root and shoot parts of the faba bean plant.

Treatment	Nodule	Leaf	Root	Nodule	Leaf	Root	Nodule	Leaf
		%N			%P		Zn (mg kg^{-1})	
UP_0Zn_0	7.3	2.9	2.1	0.43	0.66	0.16	1.42	56.8
IP_0Zn_0	6.4	3.8	2.2	0.38	0.59	0.18	1.96	78.7
UP_0Zn_1	8.2	4.3	2.4	0.49	0.76	0.43	1.89	75.8
IP_0Zn_1	6.9	5.7	2.6	0.41	0.63	0.18	2.14	86.4
UP_0Zn_2	8.3	5.4	2.9	0.50	0.77	0.41	2.16	87.3
IP_0Zn_2	7.0	6.2	2.6	0.42	0.65	0.19	2.23	89.9
UP_1Zn_0	8.0	4.3	2.3	0.48	0.74	0.24	1.99	80.1
IP_1Zn_0	6.8	6.1	2.3	0.41	0.63	0.19	2.21	88.8
UP_1Zn_1	8.1	5.5	2.5	0.49	0.76	0.29	2.25	91.2
IP_1Zn_1	7.0	6.4	2.5	0.43	0.67	0.23	2.43	93.3
UP_1Zn_2	8.3	6.3	3.0	0.51	0.79	0.30	2.28	92.0
IP_1Zn_2	7.2	6.6	2.9	0.44	0.68	0.33	2.09	84.1
UP_2Zn_0	8.0	4.9	2.4	0.49	0.76	0.26	2.18	87.9
IP_2Zn_0	7.1	6.1	2.5	0.43	0.67	0.88	2.29	91.8
UP_2Zn_1	8.4	6.1	3.0	0.51	0.79	0.31	2.37	94.7
IP_2Zn_1	8.0	6.8	3.2	0.49	0.76	0.33	2.31	97.3
UP_2Zn_2	8.4	4.5	3.0	0.52	0.80	0.32	2.14	85.4
IP_2Zn_2	8.4	6.9	3.3	0.52	0.80	0.35	2.21	88.0
LSD_I	0.213	0.099	ns	0.017	0.023	ns	0.07	1.73
LSD_P	0.261	0.121	0.022	0.021	0.029	0.022	0.09	2.12
LSD_{Zn}	0.261	0.121	0.157	0.021	0.029	0.022	0.09	2.12
R^2	0.81	0.99	0.77	0.75	0.79	0.97	0.82	0.93

ns = Not significant at P = 0.05, U= uninoculated, I= inoculated; P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}; Zn_0 = 0 kg Zn ha^{-1}, Zn_1 = 15 kg Zn ha^{-1}, and Zn_2 = 25 kg Zn ha^{-1}.

shoots, enhancing the assimilation of reduced carbon and increasing the supply of photosynthase to nodules and roots (Jakobsen, 1985). Zinc is an important plant nutrient with specific roles in nodule metabolism, plant and root growth, synthesis of chlorophyll, N-metabolism, and enzymatic processes. Thus the requirement of Zn in legumes is relatively high. Hence, the adequate concentration of Zn in the upper matured leaves and grains of legumes could reach 25 to 100 and 40 mg kg^{-1}, respectively (Fageria and Baligar, 1997).

Yield, yield components and nutrient-uptake

Significant main and interaction effects of inoculation, P and Zn fertilization were observed in this experiment, improving the grain yield, pods plant^{-1}, grain pod^{-1}, number of branches, and the grain uptake of N, P and Zn by the faba bean crop (Table 3).

Inoculation alone increased the grain yield, pods and branches plant^{-1} by 6.3, 23 and 6. 3%, and phosphorous fertilization respectively increased by 15, 27.6 and 14.8%, while zinc increased the same parameters in the same order by 10.9, 36.2 and 10.8%. Phosphorous and Zn fertilization alone increased the grain P and Zn uptake by 1.1 and 2.7 × 10^{-2} kg ha^{-1}, respectively. The combined application of inoculation, P and Zn fertilization improved the grain yield on average by 1.3 Mg ha^{-1}, which is a 54.2% increase, compared to the control. Furthermore, the combined application of the three factors increased the N. P and Zn uptake of the faba bean crop on average by 39.8, 0.54, and 9.5 × 10^{-2} kg ha^{-1}, respectively, corresponding to 102, 54 and 138% increase, compared to the control (UP_0Zn_0). The highest grain yield was obtained when Zn_1 (15 kg ha^{-1}) was fertilized with P_2 (40 kg ha^{-1}).

Similar significant improvement of grain yield, the total above-ground dry matter, pods and branches plant^{-1} of faba bean (Shibru and Mitiku, 2000; Weldu et al., 2012) and other grain legumes (Yamane and Skjelvåg, 2003; Habtegebrial and Singh, 2006) were reported by the application of P and Zn.

Phosphorous and Zn have a positive yield advantage when both are added together to soils deficient to them than adding high level of P to soils that are marginally deficient to Zn (Havlin et al., 2005). Phosphorous and Zn are found to enlarge the leaf area and improve the rate of assimilate production per unit leaf area of legumes (Yamane and Skjelvåg, 2003; Fageria, 2009), improving the yield of the crops, as they are involved in the

Table 3. Grain yield, yield components and grain nutrient uptake of faba bean.

Treatment	Grain yield (Mg ha^{-1})	Pods plant^{-1}	Grain pod^{-1}	Plant length (cm)	No. branches	Grain Nutrient uptake (kg ha^{-1})		
						N	P	Zn (x 10^{-2})
UP_0Zn_0	2.4	5.0	2.4	86.0	2.3	39.2	6.2	6.9
IP_0Zn_0	3.3	6.6	3.2	74.9	3.2	51.5	8.6	13.3
UP_0Zn_1	3.2	7.4	3.6	95.6	3.1	58.0	8.3	12.4
IP_0Zn_1	3.6	10.0	4.9	79.7	3.5	78.2	9.4	15.8
UP_0Zn_2	3.7	11.8	5.7	97.1	3.5	92.3	9.5	16.1
IP_0Zn_2	3.8	9.4	4.5	81.5	3.6	73.4	9.8	17.2
UP_1Zn_0	3.4	7.4	3.6	92.9	3.2	58.3	8.7	13.6
IP_1Zn_0	3.8	10.6	5.1	79.1	3.6	83.3	9.7	16.8
UP_1Zn_1	3.8	9.6	4.7	94.4	3.7	75.5	9.8	17.3
IP_1Zn_1	3.9	11.1	5.4	82.1	3.7	87.3	10.1	18.3
UP_1Zn_2	3.9	10.9	5.3	96.7	3.7	85.5	9.9	17.7
IP_1Zn_2	3.5	12.5	6.0	83.9	3.4	98.2	9.1	14.9
UP_2Zn_0	3.7	8.6	4.1	93.1	3.5	67.2	9.5	16.2
IP_2Zn_0	3.9	10.6	5.1	82.3	3.7	83.3	10.0	17.9
UP_2Zn_1	4.0	10.6	5.1	97.6	3.8	82.9	10.3	19.2
IP_2Zn_1	4.1	12.3	5.9	93.4	3.9	96.1	10.6	20.2
UP_2Zn_2	3.6	7.8	3.7	98.2	3.4	60.8	9.3	15.6
IP_2Zn_2	3.7	14.2	6.9	98.8	3.5	111.7	9.6	16.6
LSD_I	0.14	0.56	0.29	2.59	0.15	3.34	0.44	0.24
LSD_P	0.17	0.68	0.35	3.17	0.18	4.09	0.53	0.29
LSD_{Zn}	0.17	0.68	0.35	3.17	0.18	4.09	0.53	0.29
R^2	0.78	0.88	0.87	0.80	0.72	0.93	0.68	0.99

U = Uninoculated, I = inoculated; P_0 = 0 kg P ha^{-1}, P_1 = 20 kg P ha^{-1}, P_2 = 40 kg P ha^{-1}; Zn_0 = 0 kg Zn ha^{-1}, Zn_1 = 15 kg Zn ha^{-1}, and Zn_2 = 25 kg Zn ha^{-1}.

Table 4. Correlation analysis between grain yield and yield attributes of the plant.

Variable	By variable	*r*-Value	*P*-Value
Grain yield (g plant^{-1})	Number of pods plant^{-1}	0.72	0.0008
Grain yield (g plant^{-1})	Number of grains pod^{-1}	0.72	0.0009
Grain yield (g plant^{-1})	Number of branches plant^{-1}	0.99	<0.0001
Grain yield (g plant^{-1})	Plant height (cm)	0.16	0.52

production of chlorophyll and growth phytohormones, and photosynthetic energy transfer processes. In this experiment, the yield advantage of faba bean produced by the applied P and Zn could be attributed to an increase in the number of branches, which in turn increased the number of productive nodes and number of pods m^{-2}. The number of branches and pods plant^{-1} and the number of grains pod^{-1} of the plant, were found to strongly correlate with the grain yield (Table 4), which is consistent with the definition of yield components for legumes that determine their grain yields (Fageria, 2009).

Conclusion

Faba bean is an important source of protein and can serve as an alternative to fallow, especially in areas affected by high farmland pressure, benefiting farmers with additional income and improving or maintaining the soil's N status as the grain legume is the highest N_2-fixing crop. It is apparent in study, the N content and yield formation of faba bean was highly influenced by inoculation, P and Zn nutrition. Thus, inoculating the legume in soils devoid of efficient and compatible rhizobium, as well fertilizing with P and Zn nutrients should be recommended to soils deficient in them, especially in high alkaline calcareous semiarid soils.

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Conflict of Interest

The authors have not declared any conflict of interest.

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