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Tillage depth effects on nodulation, nitrogen fixation and yield of three soybean varieties in the Northern Savanna zone of Ghana

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Most of the farmers in the Northern Savanna zone of Ghana cannot afford the required quantities of synthetic fertilizers to apply to their crops to increase their yields. The inclusion of legumes such as soybean in the cropping systems of the zone has been found to be one of the alternatives. In order to assess the yield and Nitrogen (N) fixed by three varieties of soybean as affected by four tillage depths, a field experiment was conducted at Nyankpala in 2007 and 2008 cropping seasons. The experiment was laid in a split-plot design replicated 4 times with the main factor being tillage depths of 0, 10, 20, and 30 cm while the sub-plot treatments were soyabean varieties *(*Jenguma, Quarshie and Salintuya-2*)*. The results showed that, conventional tillage significantly ($p < 0.05$) reduced the bulk density of the soil and significantly ($p < 0.05$) increased the porosity in the 0 to 15 cm layer of the soil. There were significant influences of tillage on all the plant variables measured. Plant height, grain yield, root length density, nodules per plant and the N fixed by soybean were all highest on the deepest tillage (T_{30}) with the lowest values of these variables on the no-till plots (T_0). Among the varieties, Salintuya-2 produced significantly higher values in all the variables except plant height than Quarshie and Jenguma. However, there were no significant differences in values of these variables obtained between Quarshie and Jenguma in the experiment. Correlation analysis also showed that, grain yield was positively correlated to percent of N fixed and root length density but the relationship with plant height was not significant. Also, N content fixed was not significantly correlated to plant height. Tillage under semi-arid conditions such as found in northern Ghana is therefore necessary for high N fixation and grain yield of soybean and among the soybean varieties, Salintuya-2 is found to be the best variety in both the grain yield and N fixed in this study.

Key words: Tillage depth, soybean varieties, N fixation, cropping systems, fertilizers.

INTRODUCTION

Tillage as defined by Hillel (1980) is the mechanical manipulation of soil aimed at improving the soil conditions affecting crop production. Deep tillage increases root proliferation and the depth to which these roots can penetrate. Comparing maize yields on soils of semi-arid regions, Rasmussen (1999), found yields to be highest under deeper tillage of 90 cm compared to 40 cm depth but the least yield came from zero tillage.

Majority of the farmers in the Northern Savanna zone of Ghana prepares their lands for crop production by hand. Others use tractor or bullock ploughs while very few of them practice some sort of no-till system (SARI, 2002).

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Table 1. Characteristics of the varieties of soybean used.

Variety	Year	Days to maturity	Pod shattering	Nodule score	NDFA*(%)	Seed colour	Grain yield (t/ha)
Salintuya-2	1992	101-105	Not resistant	Good	Good	Yellow	1.2-1.8
Qurshie	2003	101-105	Resistant	Good	Good	Yellow	1.5-2.2
Jenguma	2003	>105	Resistant	V.Good	V.Good	Yellow	1.7-2.8

Source: SARI (2002). %NDFA* = The percent nitrogen derived from the atmosphere.

These tillage systems have different tillage depths and therefore may have implications on soil water content and crop yield.

It has been postulated that the number of nodules produced per plant of legumes can be reduced if root growth is limited since the total number of available potential infection sites by rhizobia would also be reduced (Ayanaba and Nangju, 1993). It is therefore envisaged that the nodulation and yield of soyabean would depend on the variety of the crop. Since tillage is considered to be location specific (Ofori, 1995; Kanton et al., 2000) it became necessary to assess the effect of tillage depths on the yield, nodulation and N fixation of some varieties of soybean commonly cultivated in the Savanna region.

Low soil fertility has been jointly identified by farmers, extensionists and researchers as one of the causes of low crop yields in the Northern Savanna zone of Ghana (RELC, 2005). This situation calls for the search for alternative methods of enhancing soil fertility for crop production since the average farmer in this zone cannot afford fertilizers because of its high cost. Soybean, a legume being one of the crops produced by the farmers in this zone, has been known to increase the fertility levels of soils due to its high nitrogen fixing ability. However, the amount of N fixed may depend on several factors of which the depth of tillage and the type of variety of the crop may be some of these factors.

The objectives of this work were therefore to assess the grain yield, number of nodules and nitrogen fixed by three soybean varieties under four different tillage depths in 2007 and 2008.

MATERIALS AND METHODS

Location and period of study

The experiment was carried out during 2007 and 2008 cropping seasons on the experimental field of the Savanna Agricultural Research Institute (SARI) at Nyankpala located in Northern Ghana (Latitute 9° 25”N, Longitute 1° 00”W and at 183 m above sea level).

The soil is sandy loam derived from Voltaian sandstone and locally known as *Tingoli* series but classified as Feric Luvisol (FAO, 1990).The soil has thin (<10 cm), brown granular and humus-stained top soil overlying a thick (>80 cm), red, clayey, highly gravelly subsoil (Alhassan, 2000). The land is gentle sloping (2%) with a pH of 6.3.

The field had been fallowed for 2 years after several years of cropping to maize/cowpea intercrop.

The climate of the site is warm semi-arid with annual monomodal rainfall of between 800 and 1200 mm which falls between May and September (SARI, 2002). This is followed by 7 months of dry season which is characterized by the dry Harmattan winds with a high risk of bush fires

Experimental design and treatments

The experiment was laid out in a split-plot design with four replications. The main plot treatments were four tillage depths: T_0, T_{10}, T_{20}, and T_{30} cm while the sub-plot treatments were three different varieties of soybean: Jenguma, Quarshie and Salintuya-2. The seeds of the 3 soybean varieties were obtained from the crop breeding section of SARI, Nyankpala. Each sub-plot measured 5 × 4 m, representing each of the 3 varieties.

The sub-plot treatments were completely randomized within the main plots and replicated 4 times.

Soil tillage operations and planting

The site was cleared off existing grasses and shrubs using cutlass and the residues were burnt in the month of May just before rains were established in each year. This was followed by the ploughing of the field with disc plough mounted on a tractor.

However, because we wanted to establish the tillage depth treatment, the tractor plough was set at different tillage depths (10, 20, and 30 cm) representing T_{10}, T_{20}, and T_{30} (the first three main factors) while the fourth no-till (T_0), the vegetation made up of grasses and shrubs were killed by Glyphosate spayed at the rate of 2.5 litres per hectare.

The subplots which were the various varieties of soybean were then allotted within the various main plots. Planting of soybean in the no-till was with the use of a cutlass to create holes for the seeds to be placed without ploughing the area.

Alongside the various soybean varieties in the subplots, maize was planted at each boarder which was used in the estimation of N fixed by each of the soybean varieties by Total Nitrogen Difference (TND) method.

Characteristics of soybean varieties used

The varieties of soybean used in the trial (Salintuya-2, Quarshie and Jenguma) are all being cultivating widely by farmers in the Northern part of Ghana. They are identified by the following characteristics as in Table 1.

The soybean varieties were sown on 10 July and 13 July in 2007 and 2008, respectively. These were sown on flat by drilling in rows on the ploughed (T_{10}, T_{20}, and T_{30}) and the on no-till (T_0) plots, and later thinned out to a spacing of 60 × 5 cm.

A net plot from the middle of each plot measuring 5.00 × 2.25 m was used for grain yield assessment.

Cultural practices

Plots were kept weed-free by hoeing manually two times before harvest at 4 and 7 weeks after planting (WAP). No fertilizer was applied to the crops.

Data collection on soil properties

Soil bulk density of 0 to 15 cm and 15 to 30 cm layers of the soil was measured using the core method and the porosity of soil in those layers determined by using a particle density of 2.65 g cm^3 (Zonn,1969) in an equation as follows:

$f = (1 - P_b/P_s) \times 100\%$.

Where, f = Porosity of the soil, P_b = bulk density, P_s = particle density

Data collected on the crops

Plant height

Before harvesting of the crops, ten soybean plants from each plot were tagged and their heights measured using a metre rule. These were summed up and the average found for each of the treatments.

Root length of soybean plants

Root development (expressed as root length (cm)) was estimated at flowering (peak of vegetative growth). Following the line intersect method by Tennant (1975). Core samples were taken at 3 depths 0 to 15, 15 to 30 and 30 to 45 cm. Core samples of root bearing soil were taken and spread using the Jarret Auger (15 cm long and 8 cm in diameter). Root samples for each soil layer were then spread out evenly on 1 cm square grid and the number of root intersections counted using a counter. The total root length for each treatment was then counted up for the whole depth and multiplied by a factor of 0.7857 and for the root length density, it was divided by the volume of the core.

Active nodule count per soybean plant

Ten soybean plants at boarder rows from each plot (outside the net plot) for each of the varieties were removed at flowering by digging around the plants and removing them gently with all the soil into containers. The detached nodules from the plants were retrieved from the soil while those still attached on the roots of the plants were then detached and counted upper plant. Each of the nodules per soybean plant was cut to determine if they were active or effective. Nodules with pinkish colour meant they were active and therefore fixing nitrogen from the atmosphere and were then counted as active nodules per plant. Those that were not pinkish in colour were discarded as they were considered non-active.

Estimation of N-fixed

The total Nitrogen Difference Technique (TND) was used in the estimating N-fixed by soybean. As described by Hassen (1994), the method is based on the total nitrogen difference between the nitrogen fixing crop (soybean) and non-nitrogen fixing crop (maize) on the same soil. The difference between the two crops (soybean and maize) per plant basis was regarded as the quantity provided by fixation.
Thus:

$$\text{N fixed} = \text{N}yield_{fix} - \text{N}yield_{ref}$$

$$\%\ \text{Ndfa} = \frac{100(\text{Nyield}_{fix} - \text{Nyield}_{ref})}{\text{N}yield_{fix}}$$

Where: % Ndfa = percentage of plant N derived from the atmosphere, N$yield_{fi}$ = N yield by fixing crop (soybean), N$yield_{ref}$ = N yield by reference crop (maize)

Grain yield and yield components

The grain yields of the soybean varieties were determined at maturity by harvesting an area of 5.00 × 2.25 m representing two rows of crops within the middle portion of each plot. The grain yields of the soybean varieties were determined at 13% grain moisture content using a weighing scale. The grain yield per plot for each variety of soybean crops was determined and expressed on a hectare basis.

Data analysis

Data were subjected to an analysis of variance for a split-plot design using GENSTAT to determine treatment effects. Treatments were considered fixed effects, years and replication were treated as random variables. Main effects and all the interactions were considered significant at $P < 0.05$. Means were separated with least significant difference (LSD) at 5% level of probability.

RESULTS

The interaction effects of year and treatments on the parameters measured

Analyzed data showed that the interaction of years with treatments were not significantly different for all the parameters measured across the years (Table 2) However, it was found that, average treatment effects were significant for soil bulk density and soil porosity both at 0 to 15 cm soil depth, nodules/plant and grain yield of soybean. In addition, year effects were significant only for soil bulk density and porosity of both soil depths (0 to 15 and 15 to 30 cm). Therefore data for such parameters are presented separately for each year. For the rest of the parameters which were not significant, these were pooled across the 2 years and only the main effects of the treatments are presented (Table 2).

Soil bulk density and soil porosity

In both years (2007 and 2008) the mean soil bulk density values for the first two tillage depths (T_0 and T_{10}) were significantly lower than the values for T_{20} and T_{30} within the 0 to 15 cm soil layer. In the reverse order, the percent soil porosity of these first two tillage depths within the same layer, were also found to be higher compared to the last two treatments (Table 3). However, in the 15 to 30 cm layer, the soil bulk density values measured among the treatments were not significantly different and the percent porosity values among treatments were also similar. Tillage therefore significantly affected both the

Table 2. Analysis of source of variance of the effects of tillage depth on the performance of three varieties of soybean across two years in the Northern Savanna zone of Ghana -2007 and 2008.

Source of variation	df	Soil bulk density (0-15 cm)	Soil bulk density (15-30 cm)	Soil porosity (0-15 cm)	Soil porosity (15-30 cm)	Plant height (cm)	Nodule/ plant	Root length density	Grain yield
Probability > f value									
Year	1	0.038	0.028	0.010	0.035	0.680	0.570	0.880	0.750
Rep (year)	6	0.064	0.135	0.072	0.118	0.025	0.625	0.028	0.689
Treatments	11	0.012	0.082	0.025	0.075	0.685	0.015	0.540	0.018
Year*Treatment	11	0.862	0.655	0.782	0.820	0.760	0.584	0.618	0.720

Table 3. Soil bulk density and porosity as affected by tillage depths.

Tillage depth	Soil bulk density (g cm^{-3})				Soil porosity (%)			
Soil depth	0-15		15-30		0-15		15-30	
(cm)	2007	2008	2007	2008	2007	2008	2007	2008
T_0	1.24^b	1.33^b	1.54	1.58	54.65^a	50.50^a	40.11	42.25
T_{10}	1.25^b	1.36^b	1.62	1.60	52.22^a	48.20^a	38.34	40.34
T_{20}	1.42^a	1.48^a	1.64	1.62	46.30^b	44.52^b	36.42	38.34
T_{30}	1.49^a	1.50^a	1.66	1.67	44.60^b	41.71^b	35.30	33.12
$LSD_{(0.05)}$	0.16	0.11	NS	NS	2.92	2.56	NS	NS

T_0 = no-till, T_{10} = tilled at 10 cm, T_{20} = tilled at 20 cm, T_{30} = tilled at 30.

Table 4. Effects of tillage depth and soybean varieties on the plant height, root length density, yield and N fixed in the Savanna region of Ghana for 2007 and 2008.

Treatment	Plant height (cm)	Effective nodules/plant	Percent N fixed ((%)	Root length density (cm.cm^3)	Grain yield (kg/ha)
T_0	28.73^c	8^c	72.80^d	0.2^d	838.54^c
T_{10}	30.45^c	11^b	77.27^c	0.4^c	1432.32^b
T_{20}	39.78^b	13^{ab}	89.22^b	0.7^b	1989.64^a
T_{30}	42.12^a	15^a	93.55^a	1.0^a	2083.30^a
SE	0.67	1	1.16	0.007	117.54
Jenguma	40.05^a	13^{bc}	63.21^b	0.90^b	780.42^b
Quarshie	38.67^{ab}	14^{ab}	65.33^b	0.92^b	785.23^b
Salintuya-2	36.82^{bc}	15^a	69.12^a	0.98^a	998.89^a
SE	1.26	1	1.01	0.004	9.24
SE-T*SV	0.89	0.34	0.67	0.0002	1.28

T_0 = no-till, T_{10} = tilled at 10 cm, T_{20} = tilled at 20 cm, T_{30} = tilled at 30 cm.

soil bulk density and soil porosity only within the 0-15 cm soil layer. Even though the depth to which tillage was applied went as deep as 30 cm for some of the treatments, both the soil bulk density and porosity within the 15 to 30 cm layer were not affected (Table 3)

Soybean parameters

Soybean plants at harvest were found to be taller on thetilled plots than the no-tilled plots (Table 4). It was further found that the soybean plants on the T_0 and T_{10} were similar in height but were both significantly ($p < 0.05$) lower in value than the shoot height of plants on T_{20} and T_{30} plots. The tallest plants were found on the deepest tillage treatment (T_{30}) which was also significantly ($p < 0.05$) higher than plants on T_{20} plots.

Comparably, grain yield was significantly higher on the tilled plots (T_{10}, T_{20}, and T_{30}) than the no-till plots (T_0). The soybean grain yields recorded on the deepest tilled plots (T_{30}) were similar to the yields obtained from the second deepest tilled plots (T_{20}). The second highest soybean

Table 5. The relationship between soybean grain yield and N fixed at Nyankpala, Ghana in 2007.

Parameter	Plant height	Grain yield	%N fixed	Root length density
Plant height	-			
Grain yield	NS	-		
% N fixed	NS	0.75**	-	
Root length density	0.65**	0.75	0.68**	-

NS = Not significant

yields were found on the T_{10} plots with the no-till plots producing the lowest yields (Table 3). However, among the soybean varieties, with the exception of Salintuya-2 which gave significantly higher yields, the yields of Quarshie and Jenguma were similar (Table 4)

The root length density and percent of N fixed followed a similar trend (Table 3). The root length density and percent N fixed as influenced by tillage depth showed the highest values of these variables on the deepest tilled plots with the lowest values on the no-till plots. Inincreasing order, which was significant at each depth was $T_{30}>T_{20}>T_{10}>T_0$. Among the soybean varieties, the results of both the root density and N fixed, showed that Salintuya-2, had the highest root density and fixed the highest N. Jenguma and Quarshie had significantly lower values for these variables than Salintuya-2. However, there were no significant differences in the variables between the Quarshie and Jenguma varieties.

The number of nodules produced by soybean plants was significantly affected by tillage depths (Table 4). The highest number of effective nodules was produced by plants on the deepest tillage treatment (T_{30}) and the lowest in the no-till treatment. However, the abundance of nodules produced by soybean plants on T_{10} and T_{20} plots were similar but were significantly lower than those on the T_{30}. Similarly, the nodules on plants on these two tillage depths (T_{10} and T_{20}) were also significantly higher than those on the no-tilled plots.

Simple correlation analysis carried out between the soybean yield and some parameters showed that grain yield was positively correlated to percent N fixed and root length density (Table 5). It further showed that the relationship between grain yield and plant height and also between percent of N fixed and plant height values were not significant.

DISCUSSION

In this study, all the tilled plots loosened the soil which resulted in significantly lower soil bulk density and high soil porosity within the 0-15 cm soil layer than in the no-till situation. The differences in soil depth created by the tillage treatments therefore reduced the soil bulk density and also significantly increased soil porosity within these plough depths than below. Observations made by Klute (1982) and Ike and Aremu (1990), which are similar to these findings showed that tillage practices in the semi-arid soils reduce bulk densities and enhance the porosities of the surface soils. The gravelly characteristics of the soil within the 15 to 30 cm and further below could partly account for the insignificant change in the bulk densities and the porosities of the soil.

The depressed soybean plant growth on the no-till plots was probably due to a reduction in root density at higher depths as a result of high soil bulk density which could have affected the efficient absorption of water and nutrients. Unger and McCalla (1980) found that, the reduction of root penetrating depth as a result of high bulk density significantly reduced plant height compared to plants on low soil bulk density soils.

Similarly, it was observed that, soybean on the no-till plots had all their nodules produced almost on the surface of the soil which most of them were not active. However, those on the tilled plots had many more effective nodules placed deeper than those found in the no-tilled conditions. Consequently, the percent N fixed measured was also lower in the no-till since the percent nitrogen fixed is positively correlated to the number of effective nodules (Kombiok, 2005). The low percent N fixed in the no-till plots in the study was therefore a reflection of the higher number of non-active nodules counted.

It could therefore be postulated that, the number of effective nodules produced and the percent N produced may depend on the depth of tillage as the plants on the deepest tilled soil (30 cm) recorded the highest number of nodules and the highest percent of N fixed. This result is consistent with the findings of Ayanaba and Nangju (1993) in which the number of nodules produced were lower on high bulk density soils compared to low bulk density soils. They attributed this situation to the reduction in root length density which limited the number of available potential infection sites by *rhizobia* as a result of high bulk density of the soil.

Among the soybean varieties, Jeguma was found to be significantly taller than both the Quarshie and Salintuya-2 varieties. However, with the grain yield, root length density, number of nodules and percent of N fixed were all significantly higher for Salintuya-2 than for Quarshie and Jenguma and this could be due to varietal differences.

It was well established that the three most important factors affecting crop yield are water, sunlight and soil nutrients (Papendick and Parr, 1997; Arshad, 1999). The effects of tillage on crop production have therefore been found to be its effects on soil parameters that influence growth, development and yield (Ernani et al., 2002). From the result of this study, deep tillage reduced soil bulk density, increased soil porosity and enhanced soil surface roughness elements. These attributes of the soil according to Shaprio et al. (2002), lead to increases in water storage, efficient water distribution, air circulation which facilitate easy access of plant roots to water and nutrients, and consequently lead to increase in crop yields.

The significantly positive correlation between grain yield and root length density and between percent N fixed by soybean plants further suggested that, the deeper the tillage, the lower the bulk density which will ease the access of the roots to both water and nutrients for high yields (Ayanaba and Nanju, 1993). Similarly, the non-significant correlation between soybean yield and plant height and also between plant height and N fixed also showed that, plant height does not directly influence the N fixed and the grain yield of soybean. This is in line with Alhassan (2000) and Kombiok (2005) who independently found deep tillage to reduce soil bulk density enhancing conditions resulting into high crop yields.

Conclusions

Based on the findings of this study, it can be concluded that, tillage under semi-arid conditions such as found in Northern Ghana is necessary for high N fixation and grain yield of soybean. Also, among the varieties tested, Salintuya-2 is found to be the best variety in terms of high grain yield and N fixed in this study.

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