Agronomic Responses to Four Tillage Variants on a Sandy-loam Ultisol cropped to Sorghum and Soybean in the derived Savanna of Southeastern Nigeria

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Abstract

The study evaluated the effects of no-till (NT) and conventional tillage (CT) left bare (B) or mulched (M) giving four treatments; NTB, NTM, CTB and CTM) on profile moisture storage, grain yield and carbon storage under sole- and intercropped sorghum and soybean in 2006 and 2007 growing seasons. In the sole sorghum, NTB and CTM enhanced moisture storage over NTM and CTB. The grain yield was lower in CTB than the other treatments. In the sole soybean, NTM and CTM enhanced moisture storage over NTB and CTB, but the differences in grain yield were consistently non-significant. In the intercropped field, moisture storage differed such that CTM > NTB > NTM = CTB. Whereas grain yield of the sorghum component followed suit, that of the soybean component remained uninfluenced. Overall, the differences in sorghum yields among the tillage methods were less pronounced in the first compared to the second year – when rainfall distribution was relatively erratic. The treatment-induced moisture explained over 60 and 72% of the variability in grain yield of the intercropped sorghum in the first and second year, respectively. In this short-term study, the CTB had the least carbon storage potential in the three cropping systems for which differences tended to be sole sorghum ≤ sole soybean ≤ intercrop. The NTB, NTM/NTB and CTM/NTB are recommended for growing sorghum, soybean and their intercrop, respectively.

Keywords: *no-till with mulch, conventional tillage, soil moisture, grain yield, carbon pool*

1. Introduction

In recent years, there has been tendency for a shift in the cultivation of sorghum (*Sorghum bicolor* L. Moench) and soybean (*Glycine max* L. Merrill) from the core savanna zones to the derived savanna zone of Nigeria due largely to drought as well as to their agronomic, economic and nutritive values (Chiroma *et al*., 2006; Lasisi and Aluko, 2009). Whereas in southwestern part of the forest-savanna transition zone, research has been undertaken on tillage need of sorghum (Agbede et al., 2008; Agbede and Ojeniyi, 2009) and soybean (Ahaneku, 2006; Lasisi and Aluko, 2009), no similar guide is available in southeastern Nigeria. Intercropping, as unfashionable as it may appear, remains the farming system among the majority of the smallholder farmers in southeastern Nigeria. Sorghum is such a resource-friendly crop that it could thrive even on marginal soils, whereas soybean has the inherent ability to nodulate freely. These attributes of the crops may be complementary and, so, are desirable under the low-input agriculture common in the zone. Most of the resource-poor farmers in the zone could take advantage of the comparatively low input requirement in the cultivation of these crops to maximize returns. The search for appropriate tillage methods for these crops should therefore not leave out intercropping.

Although there have been studies on no-till and conventional tillage without and with surface mulch in the southeastern Nigeria (Mbagwu, 1990; Ahamefule and Mbagwu, 2007), they were neither tested with the present crops nor their effects on moisture storage in crops' root zone considered. Such information is needed for sorghum and soybean, especially with fact that drought necessitated their popularity in the zone. Moreover, definition of environment-friendly agriculture should not be limited to reduction in the use of agrochemicals; sustainable crop production systems that promote carbon storage in soils are needed. The objectives of this study were: (1) to quantify the effects of no-till and conventional tillage without and with surface mulch on profile moisture storage and grain yields of sole- and intercropped sorghum and soybean (2) to establish the relationships between the treatment-induced soil moisture and the grain yields of the crops (3) to provide preliminary data on carbon storage potential of the tillage methods.

2. Materials and Methods

The experiment was carried out at the University of Nigeria Teaching and Research Farm, Nsukka (06º52' N, 07º24' E; alt. roughly 400 m asl) during 2006 and 2007 growing seasons in southeastern Nigeria. The soil properties at the site just before the initial field operations and the prevailing climate during the field study have been depicted in Table 1. In general, the area has a sub-humid climate with annual total rainfall range of 1550-1600 mm. Above 85% of the rainfall occurs during the 'wet season' (April-Oct.) which is distinct from the dry season (Nov.-March). Rainfall distribution in the wet season is usually bimodal, with peaks during July and October for the longer and shorter wet seasons, respectively. In the second year of the study, rainfall distribution was erratic compared to the first year, as shown by the rainfall analyses based on five-day intervals (Obalum *et al*., 2011a) and on daily basis (Obalum *et al*., 2011b). The soil belongs to Nkpologu series and has been classified using the Keys to Soil Taxonomy as Typic Paleustult, with ustic moisture regime and isohyperthermic thermal regime (Soil Survey Staff, 2006). At the study site, the landscape has a gentle slope (about 1-2%) and underlain by deep and well-drained red to brownish red soil. For about 10 years before the experiment, the field was under mixed grass-legume fallow.

The experiment involved factorial combination in a split-plot of no-till (NT) and conventional tillage (CT) without or with surface mulch –, i.e., left bare (B) or mulched (M), respectively. This gave four treatments (NTB, NTM, CTB and CTM) regarded as tillage methods, which were replicated four times in a randomized complete block design (RCBD). Effects of the tillage methods were evaluated concurrently in three adjacent but separate cropping systems (sole sorghum, sole soybean and their intercrop). The procedures for the field establishment and for the standard laboratory analyses of soil samples have been fully described elsewhere (Obalum and Obi, 2010). Notable among the procedures is that the NT plots were just clean-weeded flat beds while the CT were seedbeds manually prepared by ploughing to depths of about 20 cm using a traditional African hoe. The methods employed in the determination of profile moisture storage in the 50-cm soil depth, the agronomic and cultural practices and crop husbandry, and the methods used to assess the grain yields have all been described in Obalum *et al*., (2011a, b). Key agronomic information in the cited references is that the test crops were late-maturing sorghum cultivar (SAMSORG-16 FFBL) and early-maturing soybean cultivar (SAMSOY-2). At the end of the study, soil organic carbon (C) pool under the treatments was calculated thus:

C pool (Mg ha^{-1}) = %C/100 × bulk density (Mg m^{-3}) × hectare area (m^2) × soil depth (m).

All the data were subjected to analysis of variance (ANOVA) suitable for a split-plot in RCBD using the computer software, GENSTAT Discovery Edition 3.

3. Results and Discussion

3.1 Profile soil moisture storage

Figure 1 shows the mean values of the periodically monitored moisture storage in the root zone of the crops as influenced by the tillage methods. In the sole sorghum field, the NTB and the CTM stored significantly ($P \leq 0.05$) higher soil moisture than the NTM and the CTB. This was more evident in the second year (when rainfall was erratically distributed) than in the first year (when rainfall distribution was normal). In the sole soybean field, moisture storage significantly ($P \leq 0.05$) decreased from the NTM and the CTM through the CTB to the NTB. Similar to the sole sorghum field, this was more evident in the second than in the first year. Notably, the NTB and the NTM swopped positions in the sole sorghum and the sole soybean fields. In the intercropped field, the tillage methods differed thus CTM > NTB > NTM = CTB, and this was more evident in the first than in the second year.

The consistently high moisture storage in the CTM is attributed partly to the surface-modifying effect of CT (Omer and Elamin, 1997) and partly to the reduced evaporative losses due to the presence of mulch. The similarity in effects of the CTM and the NTB in the sole sorghum field suggests that the NT, unlike the CT, is not compatible with surface-applied mulch for conserving soil moisture under sorghum in this soil. On the other hand, the CTM and the NTM produced similar effects in the sole soybean plot. This implies that mulch would be effective at the same scale with the NT as with the CT under soybean in this soil. Out of the three fields, only in the sole soybean field did the saturated hydraulic conductivity differ at the end of the study between the mulch (NTM/CTM) and the bare (NTB/CTB) plots, which showed moderate and rapid values respectively (Obalum and Obi, 2010). This more favourable soil hydraulic property in the mulch treatments than in the bare treatments under soybean would explain the higher moisture storage in the former than in the latter. Furthermore, the higher moisture storage in the CTB than in the NTB under soybean most probably stemmed from the enhanced rainwater infiltration into the former due to the presence of large clods and larger surface area (Hatfield *et al*., 2001; Ali and Talukder, 2008). The fact that this prevailed only in the bare plots substantiates the remark that surface mulch could nullify the differing effects of NT and CT on soil moisture in the sole soybean field.

Following a long term study of a set of tillage treatments identical to the ones under investigation, Opara-Nadi and Lal (1986) reported that moisture available within the first 40 cm depth of an Alfisol under maize (*Zea mays*) in southwestern Nigeria followed the order, NTM > NTB = CTM > CTB. In the present study, the low moisture status of the NTM in the sole sorghum and the intercropped plots was due probably to the poor aggregation and weak structure of the soil (Aina, 1993). Despite the fact that this structural defect was most pronounced in the sole soybean field at the end of the study (Obalum and Obi, 2010), the NTM enhanced soil moisture storage in this field. Unlike in the sole sorghum and the intercropped fields, there prevailed almost complete shading of the soil under soybean by the well established canopy of the crop. Such a crop canopy structure was presumably needed to encourage more infiltration and storage of the rainwater intercepted and retained at the near-surface by the applied mulch. There are many reports which imply that the wetter an environment is, the more pronounced would be the beneficial effects of the NTM in soil moisture conservation (Aina, 1993; Babalola and Opara-Nadi, 1993; Opara-Nadi, 1993).

3.2 Grain yields of the crops

3.2.1 Sole- and intercropped sorghum

The grain yields of the crops in both sole- and intercropping are shown in Table 2. For sorghum, the grain yield in the sole-cropped field was significantly ($P \leq 0.01$) lower in the CTB than in the rest of the treatments–NTB, NTM and CTM for which values were statistically comparable–in the second year of the study. Averaged over the two years, the results showed significant ($P \leq 0.05$) differences in a pattern same as that in the second year, i.e., lower yield in the CTB than in the rest of the tillage methods. Notably, the NTM out-yielded the CTB, in spite of their similar status of soil moisture storage. The yield advantage of the NTM over the CTB corroborates some previous tillage experiments with other cereals in the present location (Mbagwu, 1990; Obi and Nnabude, 1990) and elsewhere in Nigeria (Lal, 1995; Alhassan *et al.,* 1998). Similar results have been reported specifically for sorghum in Ethiopia (Mesfine *et al.*, 2005) and in another sandy loam in the derived savanna of southwestern Nigeria (Agbede and Ojeniyi, 2009). However, whereas Mesfine *et al.* (2005) reported higher grain yield in the NTM than the NTB, Agbede and Ojeniyi (2009) found, similar to the present study, no differences between the two treatments. It appears therefore that the NT may or may not be combined with mulch (NTB or NTM) for growing sorghum in the Nigerian derived savanna. On the contrary, the CT needs mulch (CTM) to give similar grain yield as the NTM (Mesfine *et al.*, 2005).

In the intercropped field, the CTM consistently out-yielded the NTB, NTM and CTB. Although the yield showed an overall trend of decreasing among the treatments in the order just listed, the CTM and the NTB differed significantly ($P \leq 0.05$) only in the second year (with erratic rainfall distribution). Notably too, the grain yields in the NTB, NTM and CTB were generally comparable. Main effects of the tillage factors in the sole-cropped field showed significant ($P \leq 0.05$) yield increase in the NT treatments over their CT counterparts in the second the year. This may be attributed to the protection against the short-duration droughts in the second year in the NT compared to the CT, especially with the reported ability of the NT to improve moisture storage and lower soil temperatures early in the season (Opara-Nadi, 1993; Anikwe and Ubochi, 2007). These results imply that the NT could mitigate the negative effects of adverse growing conditions in a comparatively dry year (Bescansa *et al*., 2006; De Vita *et al*., 2007). The enhanced yield with the NT is in good agreement with the results reported for sorghum grown in another sandy loam in southwestern Nigeria (Agbede *et al.*, 2008).

On the other hand, the mulch treatments consistently out-yielded their bare counterparts. The differences were significant ($P \leq 0.05$) in the sole- and the intercropped sorghum fields respectively in the first and the second year with contrasting rainfall patterns. These results suggest that, in this environment often characterized by hydroclimatic vagaries, the manifestation or otherwise of the moisture-conserving benefit of mulch on sorghum grain yield may depend not just on rainfall pattern but also on other factors as may be induced by cropping system. Mbagwu (1991) who also reported an increase in grain yield of maize in the present location attributed the observation to moderating effect of mulch on soil temperature. The present results corroborate other reported increases with mulch in grain yields of cereals in other sub-humid tropical environments (Moitra *et al.,* 1996; Ghuman and Sur, 2001), and of specifically sorghum in the semi-arid tropics where the bulk production of the crop is done (Mesfine *et al.,* 2005; Chiroma *et al.,* 2006).

3.2.2 Sole- and intercropped soybean

For soybean, the data in Table 2 show that the differences in the grain yields in both the sole- and the intercropped fields due to the tillage methods were not significant in either of the two years. Some other studies elsewhere which found soybean to be non-responsive to tillage systems (Yusuf *et al.,* 1999; Koga and Tsuji, 2009; Rodrigues *et al.*, 2009), as well as a review of the effects of tillage methods on crop grain yields (Alvarez and Steinbach, 2009), all lend credence to these results. Yusuf *et al.* (1999) showed that soybean in NT exhibited compensatory reproductive growth to the early season plant development in CT, thereby minimizing yield differences between the two tillage systems.

Although the tillage-induced differences in grain yields were not appreciable, the NT treatments out-yielded the CT treatments by 16.2% in the sole-cropped field in the second year that was implicated with unfavourable rainfall pattern. Singer *et al.* (2008), who reported inconsistent results over a three-year period, equally observed that years with unfavourable rainfall favoured NT. In contrast, similar increase in the NT over the CT in the intercropped field occurred in the first not the second year. This underscores the aforementioned relevance of cropping system in determining the effects of soil management practices under contrasting rainfall patterns. The results of the present study differ from the higher yield with CT reported for soybean by Lasisi and Aluko (2009) in southwestern Nigeria, despite the similarity in soil textural attribute of the present location to that of their study. The disparity is attributed mainly to the fact that, unlike the manual CT in this study which rarely exceeded the top-(20 cm) soil, Lasisi and Aluko (2009) used tractor-mounted implements to achieve deeper and more intensive ploughing and harrowing.

3.3 Influence of the treatment-induced soil moisture on the grain yields

Figure 2 shows that, with the exception of the intercropped sorghum, the relationships between soil moisture storage and grain yields were weak. In the sole sorghum field, the treatments differed in soil moisture storage in both years of the study but in grain yield only in the second year. Besides, the NTM and the CTB were similar in moisture storage, but the former out-yielded the latter in the said second year. Hence, the relationship was weaker in the first year ($r = 0.125$) than in the second year ($r = 0.305$). In contrast, moisture storage and grain yield among the treatments followed similar trend in the intercropped sorghum field. The treatment-induced soil moisture accounted for above 60 and 72% of the variability in yield of intercropped sorghum in the first and second year, respectively (Figure 2a). This is yet another pointer to the relevance of cropping system in the agronomic response to the tillage methods under study in this environment.

In the case of soybean, neither in the sole- nor in the intercropped field did the moisture storage influence the grain yield (Figure 2b). Similar to the majority of the results reported, Anikwe *et al*. (2003) showed how seasonal variations in moisture contents as induced by different soil and crop management practices had no influence on maize grain yield in the present location. Generally, the weak control of the treatment-induced soil moisture over the grain yields was more evident in the first than in the second year. Since the crops followed a fallowed land in the first but not the second year, the cropping history was plausibly 'favourable' in the first relative to the second year. This might have had a greater masking effect on the treatment-induced differences in soil moisture on the crop's grain yields in the first than the second year (Agriculture and Rural Development, 2004).

From the foregoing, it could be inferred that the differences among the tillage methods in soil moisture storage could not always manifest in–or be of the magnitude to influence–the crops' grain yields (Aboudrare *et al*., 2006; Anikwe and Ubochi, 2007). Other than the treatment-induced differences in soil moisture storage in the monitored profile, some probable reasons behind the yield results in the sole-cropped fields have been discussed elsewhere for sorghum (Obalum *et al*., 2011a) and for soybean (Obalum *et al*., 2011b).

3.4 Between the first and the second year

The grain yield of sorghum was higher in the first than the second year and vice versa for soybean (Table 2). On the average, the sole- and the intercropped sorghum showed about 52 and 66% decline in grain yield in the second relative to the first year. In contrast, the sole- and the intercropped soybean showed about 53 and 59% increase in grain yield in the second relative to the first year. Since crop management was the same in both years, the observed disparity in grain yield may be the result of differences in environmental conditions during critical growth stages (Laddha and Totawat, 1997). Sorghum yields, for instance, vary considerably between years with a close dependence on rainfall distribution, hence the decline in the second year when rainfall was erratically distributed compared to the first year (Mesfine *et al*., 2005; Stone and Schlegel, 2006). The crop actually experienced a short dry spell during the critical stage of high water demand in the second but not the first year (Obalum *et al*., 2011a). Conversely, soybean pod development coincided with 'the normal short break in rainfall in the area' in the first year; only in the full bloom stage characterized by lowest water demand was water limiting in the second year (Obalum *et al.*, 2011b). Although our analyses revealed that water deficit during the respective critical stages of development was largely responsible for the phenomena, other factors bordering on agronomic practices and soil reaction were equally implicated (Obalum *et al.*, 2011a; 2011b).

3.5 Soil organic carbon pool under the tillage methods

At the end of the two-year study, the CTB showed to be the tillage method with the least potential to enhance organic carbon pool in the topsoil of the three cropping systems (Figure 3). Notably, the NT treatments (NTB and NTM) generally improved the carbon pool over the CT treatments (CTB and CTM). The differences among the NTB, NTM and CTM were, however, nominal except in the intercropped field where the NTB and the NTM showed higher carbon pool than the CTM. The data in Figure 3 also suggest that, irrespective of tillage method, the most likely trend of the influence of the cropping systems on carbon storage in this location is sole sorghum ≤ sole soybean ≤ intercrop. The data presented should be seen as merely giving an insight into carbon storage in cultivated agricultural soils in the study zone; more reliable data on especially such a valid topic as carbon storage potential need to come from long-term cultivated fields/observatories. Such studies are expected to allow for the expression of the tillage method (from among the NTB, NTM and CTM) with the greatest potential for enhancing soil carbon storage in each cropping system. Such information is particularly important for the intercropping system where the NTB/NTM generally showed lower sorghum yield but higher carbon pool than the CTM.

4. Conclusions

With regard to profile soil moisture storage and grain yields in sole-cropping, the NTB and the NTM are respectively recommended for growing sorghum and soybean. However, the treatment-induced soil moisture had weak influence on the grain yields of sole-cropped sorghum and soybean. Soil moisture storage but not grain yield was lower in the NTB than the NTM under soybean. The weak relationship between soil moisture and grain yields thus renders the NTB a close substitute of the NTM for growing soybean, unless when the extra moisture conserved in the NTM has other agronomic and environmental benefits. In intercropping system with sorghum as the farmer's base crop, either of the NTB and the CTM would be suitable for enhancing grain yields of both component crops in the system. The treatment-induced soil moisture influenced the grain yields of the sorghum but not the soybean component. Although the NTB is socio-economically more attractive than the CTM, the latter may by virtue of its moisture-storage advantage over the former be the better option for enhancing grain yield of the sorghum component in especially years of erratic rainfall.

In the three cropping systems, the CTB showed to be the tillage method with the least potential of increasing grain yields and carbon storage in the structurally fragile soil studied. The sustainability of especially the NTB and the data on carbon storage potential of the tillage methods in the cropping systems need to be validated through long-term trials.

References

Aboudrare A., Debaeke P., Bouaziz A., Chekli H. 2006. Effects of soil tillage and fallow management on soil water storage and sunflower production in a semi-arid Mediterranean climate. Agric. Water Manage. 83: 183-196.

Agbede T.M., Ojeniyi S.O. 2009. Tillage and poultry manure effects on soil fertility and sorghum yield in southwestern Nigeria. Soil Tillage Res. 104: 74–81.

Agbede T.M., Ojeniyi S.O., Awodun M.A. 2008. Effect of tillage method on growth, grain yield and nutrient content of sorghum (*Sorghum bicolor* L.) in forest savanna transition zone of Nigeria. Int. J. Sustainable Crop Prod. 3: 35-39.

Agriculture and Rural Development 2004. Tillage Effects on Soil Moisture. Government of Alberta, Canada. Available at:

http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/eng8174/$file/Tillage_Effects_on_Soil_Moisture.pdf?OpenElement

Ahamefule H.E., Mbagwu J.S.C. 2007. Effects of phosphorus and four tillage mulch systems on the physico-chemical properties of an Ultisol in eastern Nigeria. Agro-Science 6: 25-32.

Ahaneku I.E. 2006. Influence of tillage method on emergence and yield of soybean. Discovery and Innovation 18: 30-36.

Aina P.O. 1993. Rainfall runoff management techniques for erosion control and soil moisture conservation. In: *Soil Tillage in Africa: Needs and Challenges. FAO Soils Bulletin, 69*. Food and Agricultural Organization of the United Nations, Rome, Italy.

Alhassan A.B., Kundiri A.M., Folorunso, O.A. 1998. Water use efficiency of millet as influenced by different tillage and residue management practices in Northeast Nigeria. J. Arid Agric. 8: 45-51.

Ali M.H., Talukder M.S.U. 2008. Increasing water productivity in crop production – A synthesis. Agric. Water Manage. 95: 1201-1213.

Alvarez R., Steinbach H.S. 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. Soil Tillage Res. 104: 1-15.

Anikwe M.A.N., Ubochi J.N. 2007. Short-term changes in soil properties under tillage systems and their effect on sweet potato (*Ipomea batatas* L.) growth and yield in an Ultisol in south-eastern Nigeria. Aust. J. Soil Res. 45: 351–358.

Anikwe M.A.N., Obi M.E., Agbim N.N. 2003. Effect of crop and soil management practices on soil compactibility in maize and groundnut plots in a Paleustult in Southeastern Nigeria. Plant Soil 253: 457-465.

Babalola O., Opara-Nadi O.A. 1993. Tillage systems and soil properties in West Africa. Soil Tillage Res. 27: 149-174.

Bescansa P., Imaz M.J., Virto I., Enrique A., Hoogmoed W.B. 2006. Soil water retention as affected by tillage and residue management in semiarid Spain. Soil Tillage Res. 87: 19-27.

Chiroma A.M., Folorunso O.A., Alhassan A.B. 2006. Soil water conservation, growth, yield and water use efficiency of sorghum as affected by land configuration and wood-shavings mulch in semi-arid northeast Nigeria. Exp. Agric. 42: 199-216.

De Vita P., Di Paolo E., Fecondo G., Di Fonzo N., Pisante M. 2007. No-till and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. Soil Tillage Res. 92: 69-78.

Ghuman B.S., Sur H.S. 2001. Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a subhumid subtropical climate. Soil Tillage Res. 58: 1-10.

Hatfield J.L., Sauer T.J., Prueger J.T. 2001. Managing soils to achieve greater water use efficiency: A review. Agron. J. 93: 271-280.

Koga N., Tsuji H. 2009. Effects of reduced tillage, crop residue management and manure application practices on crop yields and soil carbon sequestration on an Andisol in northern Japan. Soil Sci. Plant Nutr. 55: 546-557.

Laddha K.C., Totawat K.L. 1997. Effects of deep tillage under rainfed agriculture on production of sorghum (*Sorghum bicolor* L. Moench) intercropped with green gram (*Vigna radiata* L. Wilczek) in western India. Soil Tillage Res. 43: 241-250.

Lal R. 1995. Tillage and mulching effects on maize yield for seventeen consecutive seasons on a tropical Alfisol. J. Sustainable Agric. 5: 79-93.

Lasisi D., Aluko O.B. 2009. Effects of tillage methods on soybean growth and yield in a tropical sandy loam soil. Int. Agrophy. 23: 147-153.

Mbagwu J.S.C. 1990. Mulch and tillage effects on water transmission characteristics of an Ultisol and maize and cowpea yield in southeastern Nigeria. Pedologie 40: 155-168.

Mbagwu J.S.C. 1991. Mulching an Ultisol in southern Nigeria: Effects on physical properties and maize and cowpea yield. J. Sci. Food Agric. 57: 517-526.

Mesfine T., Abebe G., Al-Tawaha A.M. 2005. Effect of reduced tillage and crop residue ground cover on yield and water use efficiency of sorghum (*Sorghum bicolor* [L.] Moench) under semi-arid conditions of Ethiopia. World J. Agric. Sci. 1: 152 - 160.

Moitra R., Ghosh D.C., Sarkar S. 1996. Water use pattern and productivity of rainfed yellow sarson (*Brassica rapa* L. var *glauca*) in relation to tillage and mulching. Soil Tillage Res. 38: 153-160.

Obalum S.E., Amalu U.C., Obi M.E., Wakatsuki, T. 2011a. Soil water balance and grain yield of sorghum under no-till versus conventional tillage with surface mulch at the derived savanna zone of southeastern Nigeria. Exp. Agric. (in press).

Obalum S.E., Igwe C.A., Obi M.E., Wakatsuki, T. 2011b. Water use and grain yield response of rainfed soybean to tillage-mulch practices in southeastern Nigeria. Scientia Agricola (in press).

Obalum S.E., Obi M.E. 2010. Physical properties of a sandy loam Ultisol as affected by tillage-mulch management practices and cropping systems. Soil Tillage Res. 108: 30 - 36.

Obi M.E., Nnabude P.C. 1990. Testing tillage variants on a sandy loam soil (dystric nitosol) in Nigeria as regards soil conservation, yield, and water utilization. Beitrage zur Tropischen Landwirtschaft und Veterinarmedizin 28: 291-302.

Omer M.A., Elamin E.M. 1997. Effect of tillage and contour diking on sorghum establishment and yield on sandy clay in Sudan. Soil Tillage Res. 43: 229-240.

Opara-Nadi O.A., Lal R. 1986. Effects of tillage methods on physical and hydrological properties of a tropical Alfisol. Zeitschrift fur Pflanzenernahrung und Bodenkunde 149: 235-243.

Opara-Nadi O.A. 1993. Conservation tillage for increased crop production. In: *Soil Tillage in Africa: Needs and Challenges. FAO Soils Bulletin, 69*. Food and Agricultural Organization of the United Nations, Rome, Italy.

Rodrigues J.G.L., Gamero C.A., Fernandes J.C., Miras-Avalos J.M. 2009. Effects of different soil tillage systems and coverages on soybean crop in the Botucatu Region in Brazil. Spanish J. Agric. Res. 7: 173-180.

Singer J.W., Logsdon S.D., Meek D.W. 2008. Soybean growth and seed yield response to tillage and compost. Agron. J. 100: 1039-1046.

Soil Survey Staff 2006. Keys to Soil Taxonomy (10th ed.) Natural Resources Conservation Services, United States Department of Agriculture, Washington D.C, USA.

Stone L.R., Schlegel A.J. 2006. Yield-water supply relationships of grain sorghum and winter wheat. Agron. J. 98: 1359-1366.

Yusuf R.I., Siemens J.C., Bullock D.G. 1999. Growth analysis of soybean under no-tillage and conventional tillage systems. Agron. J. 91: 928-933.

Table 1: Selected physicochemical properties of the top-(0-10 cm) soil before the study and climatic variables during the growing seasons

Soil property	Value	Month	Rainfall (mm)		
			2006	2007	20-year† mean
Sand (g kg^{-1})	752	June	260	328	155
Silt (g kg^{-1})	160	July	214	63	246
Clay (g kg^{-1})	88	Aug.	196	324	230
Textural class	Sandy loam	Sept.	191	170	285
Bulk density (kg m^{-3})	1460	Oct.	314	267	200
Total porosity (%)	57	Nov.	2	55	30
MWD (mm)	2.3	Dec.	0	0	0
Moisture content at 0.06-bar tension (%)	45		Rel. humidity (%)		Mean‡ air temp. ± std. dev. (°C)
			2006	2007	
K_{sat} (mm h^{-1})	83	June	77.7	77.5	25.6±0.0
pH in water	6.6	July	79.7	78.7	25.0±0.1
OC content (g kg^{-1})	5.0	Aug.	80	79.1	24.6±0.4
Total N (g kg^{-1})	1.1	Sept.	79.1	78.1	24.8±0.0
Available P (mg kg^{-1})	28	Oct.	76.9	76.6	25.4±0.4
CEC (cmol kg^{-1})	7.0	Nov.	65.5	76.3	25.7±0.4
Taxonomy	Ultisol	Dec.	57.2	69.4	25.6±0.4

†1971-1990, Source: Igwe cited in Obalum *et al.* (2011a); ‡For the two years of the study
MWD – mean weight diameter; K_{sat} – saturated hydraulic conductivity
OC – organic carbon; CEC – cation exchange capacity

Table 2: Grain yields of sole- and intercropped sorghum and soybean under the various tillage methods in the two years of the study

Tillage Methods	Grain yield (Mg ha^{-1})					
	2006	2007	Mean	2006	2007	Mean
	Sole-cropped sorghum			Sole-cropped soybean		
NTB	1.14	0.70	0.92	0.71	1.54	1.13
NTM	1.21	0.63	0.92	0.81	1.91	1.36
CTB	0.87	0.32	0.60	0.71	1.22	0.97
CTM	1.41	0.58	1.00	0.81	1.73	1.32
LSD	ns	0.16**	0.18*	ns	ns	ns
	Intercropped					
	Sorghum			and Soybean		
NTB	1.34	0.36	0.85	0.31	0.68	0.50
NTM	0.98	0.38	0.68	0.27	0.65	0.46
CTB	0.87	0.26	0.57	0.23	0.58	0.41
CTM	1.59	0.64	1.12	0.26	0.71	0.48
LSD	0.42**	0.22*	0.41**	ns	ns	ns

NTB – no-till, bare; NTM – no-till, mulch;

CTB – conventional tillage, bare; CTM – no-till, bare

Note: ns stands for 'not significant' at $P \leq 0.05$;

where significant, * and ** denote $P \leq 0.05$ and 0.01, respectively

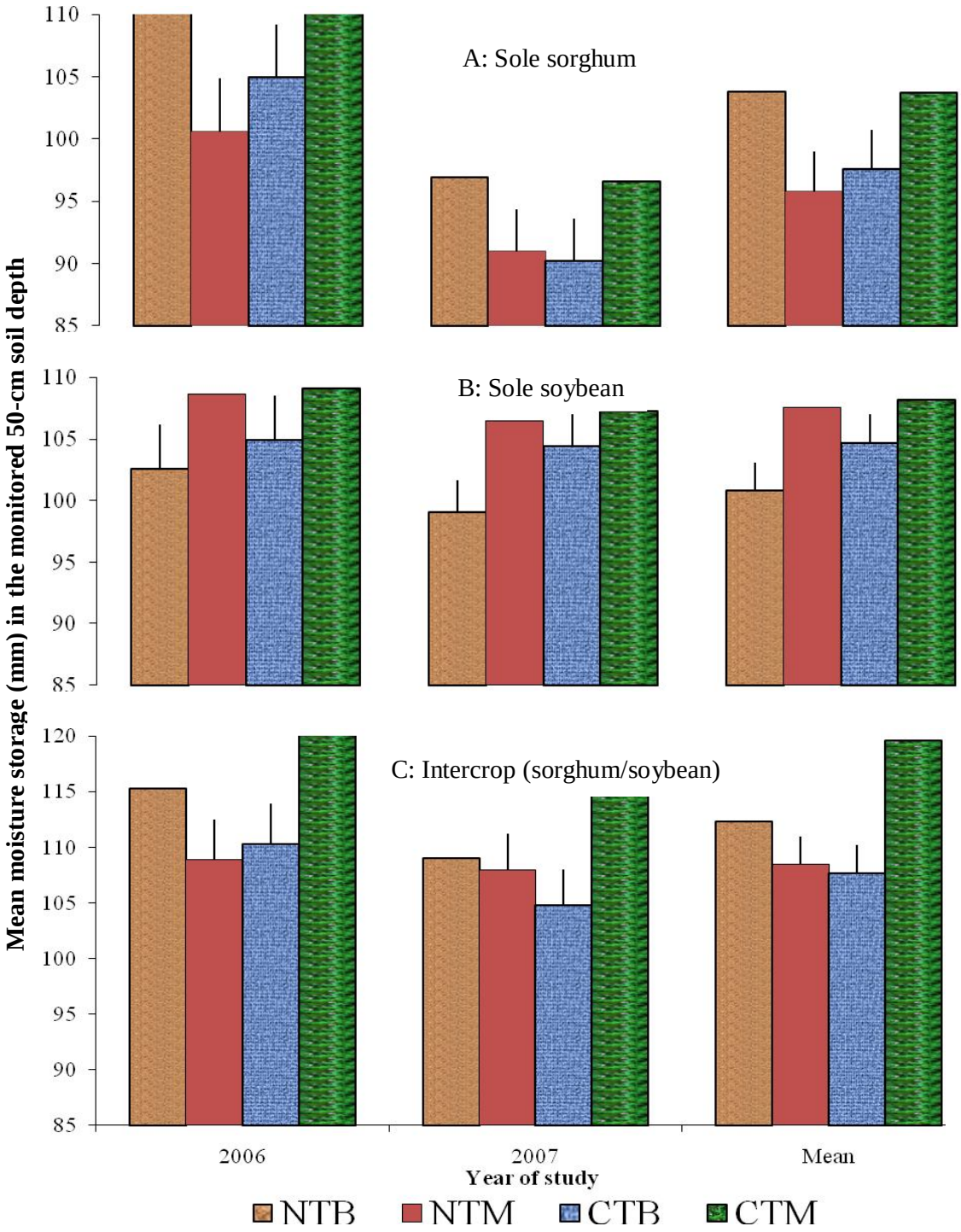


Figure 1: Mean† soil moisture per 50-cm profile depth under the various tillage methods in the three cropping systems in both years of the study.
NTB – no-till, bare; NTM – no-till, mulch; CTB – conventional tillage, bare; CTM – no-till, bare
Vertical error bars represent the $LSD_{(0.05)}$ among the tillage methods.
†Of all the values as monitored for 11 and 9 times (for the sole sorghum field and the sole soybean and intercropped fields, respectively) at 10±day intervals across the growing seasons

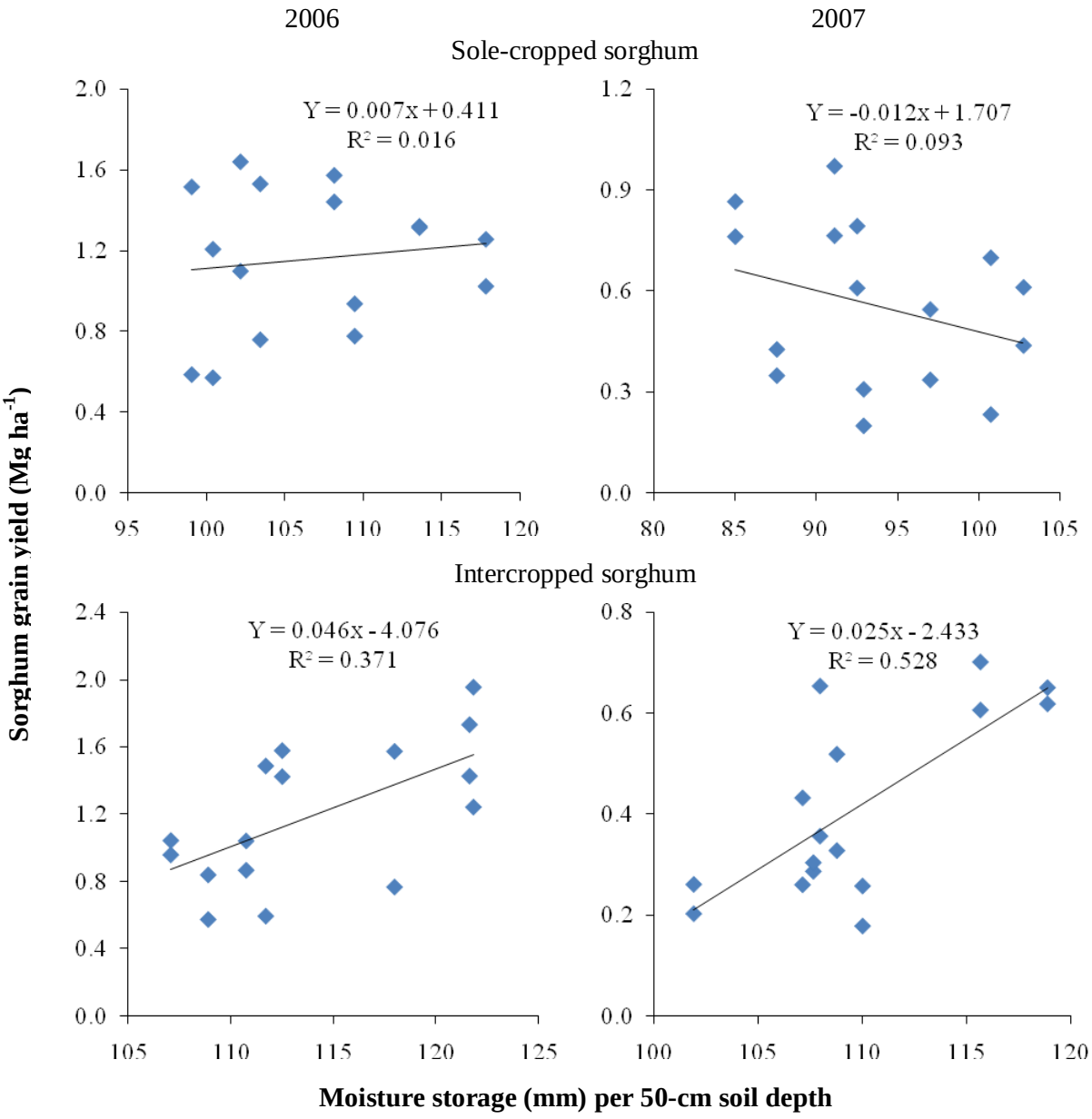


Figure 2a: Linear relationship between sorghum grain yield and soil moisture storage

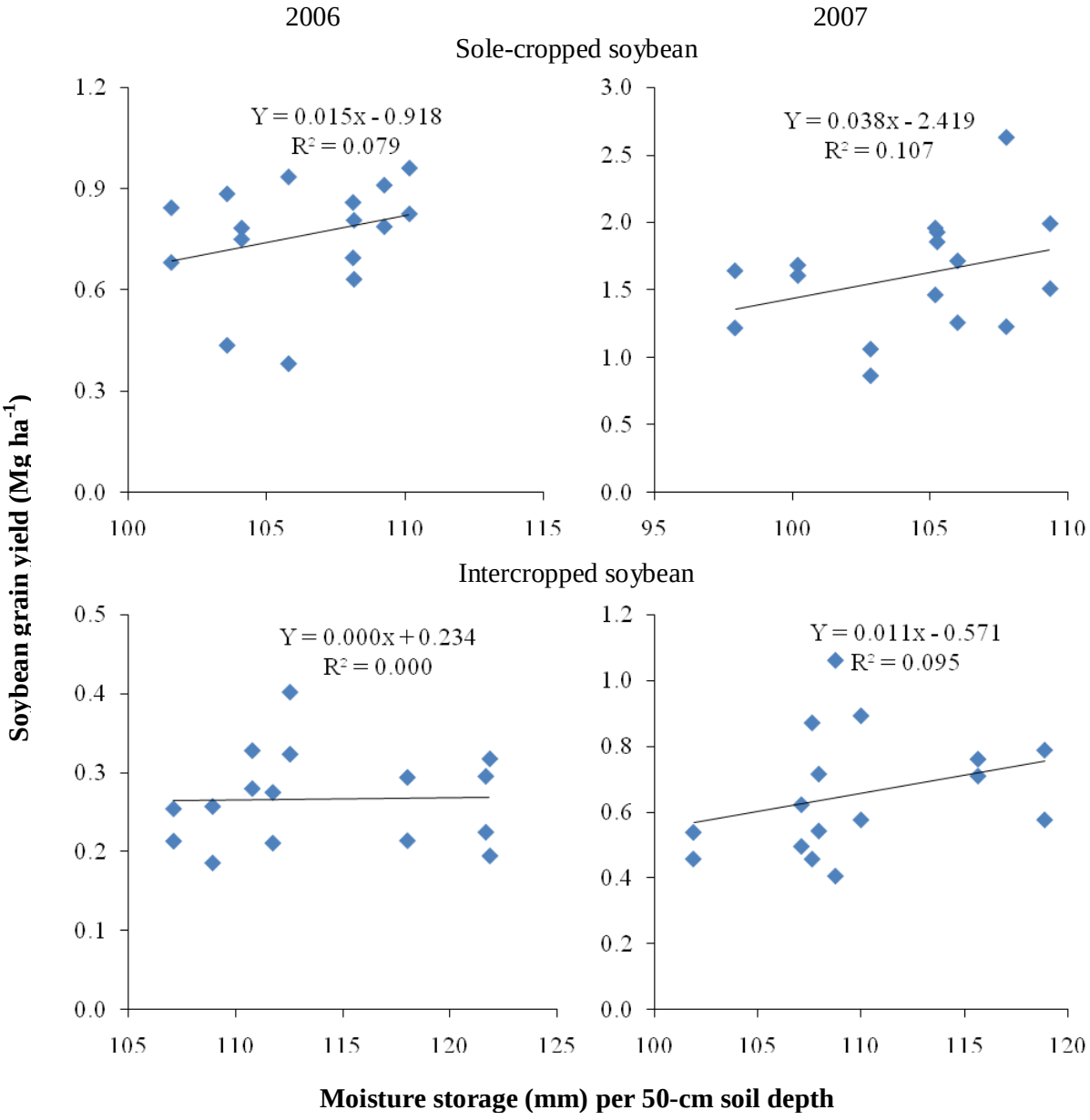


Figure 2b: Linear relationship between soybean grain yield and soil moisture storage

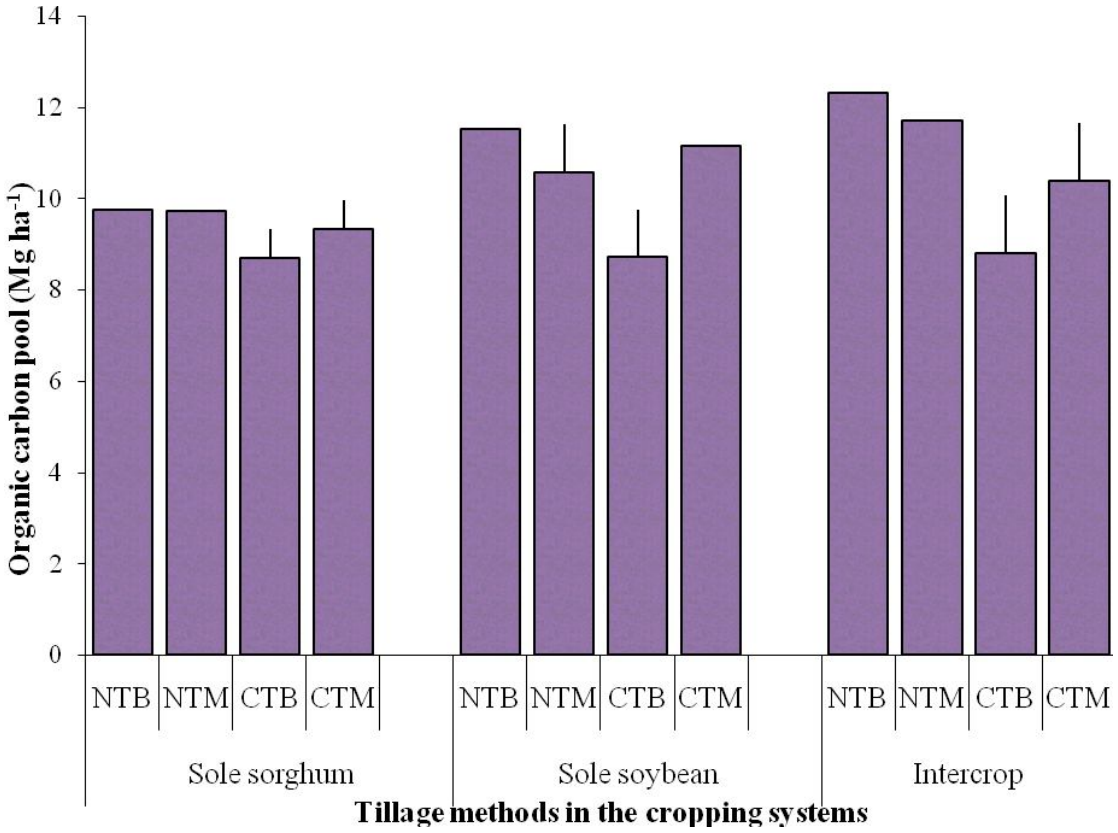


Figure 3: Organic carbon pool in the top-(0-10 cm) soil under the various tillage methods in the three cropping systems at the end of the two-year study.
NTB – no-till, bare; NTM – no-till, mulch; CTB – conventional tillage, bare; CTM – no-till, bare
Vertical error bars represent the $LSD_{(0.05)}$ among the tillage methods.