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Effect of soil compaction and organic matter on the early growth of maize (*Zea mays*) in a vertisol

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A b s t r a c t. A laboratory experiment was conducted to determine the emergence and early growth of maize (*Zea mays*) seeds in a dark clay soil known as vertisol (Typic Pellustert). Three quantities of groundnut haulms were incorporated into the vertisol as organic matter and then compacted at three moisture content levels using four different compactive efforts. The three organic matter and moisture content levels were 2, 4 and 6% (db), and 20, 35 and 50% (w/w), respectively. The four compactive efforts were 0, 5, 10 and 15 proctor hammer blows. Soil properties determined were soil bulk density and penetration resistance while crop parameters were emergence count, plant height, shoot moisture content, dry weight of shoots and roots and root length.

For all soil moisture content and hammer blows, soil bulk density and penetration resistance decreased with increase in organic matter level. Maximum values of soil bulk density and penetration resistance were recorded at 10 hammer blows, 2% organic matter and 35% soil moisture content levels, respectively. The plant parameters gave their highest values at 5 hammer blows, 4% organic matter and 35% soil moisture content levels, respectively.

The results obtained in this study showed that there is a great potential in managing the soil by the addition of organic matter as a means of alleviating the problems of soil compaction for the development and growth of crops such as maize. The influence will however depend on the soil type, amount of organic matter added, soil moisture content at the time of load application and the amount of load applied.

K e y w o r d s: vertisol, organic matter, compaction, maize, early growth

INTRODUCTION

The ever increasing need of food for the millions of human beings on earth has encouraged producers to mechanize farm operations. The use of heavy equipment and repeated passes on agricultural fields leads to soil compaction. Compaction is the densification of soils through the application of mechanical energy resulting in a reduction of pore spaces. Soil compaction has negative effects on seed emergence (Montemayor, 1995; Radford *et al*., 2000; 2001); yield and yield parameters of crops (Alakukku and Elonen, 1995; Alblas *et al*., 1994; Boone *et al*., 1994; Hadas *et al*., 1986; Onofiok, 1989; Radford *et al*., 2001). Soil compaction has significant effects on soil physical, chemical and biological properties (Carman, 2002; Diaz-Zorita and Grosso, 2000; Lipiec and Stępniewski, 1995; Whalley *et al*., 1995). Mechanical resistance and poor aeration may restrict root growth, which especially affects the uptake of nutrients (Czyż and Tomaszewska, 1993; Lal, 1996; Lipiec and Hatano, 2003; Lipiec and Stępniewski, 1995; Lipiec *et al*., 1991). Bengough and Mullins (1990) reported that for most agricultural crops, root growth could slow down drastically when cone penetration resistance exceeds approximately 2 MPa.

Although certain amount of soil compaction is required to ensure better contact between seeds and soil particles (Agrawal, 1991; Kayombo and Lal, 1993; Mamman and Ohu, 1998; Ohu and Folorunso, 1989; Onwualu and Anazodo, 1989), any extra compaction increases soil strength and could cause several problems. Harmful effects of soil compaction on soil structure include reduction of air filled void spaces, reduction of the volume of macropores, changes in soil matrix gaseous composition and increases in resistance to root growth and configuration (Håkansson and Lipiec, 2000; Lipiec *et al*., 1998; Logsdon *et al*., 1987; Lowery and Schuler, 1994).

Soil compaction caused by agricultural traffic is commonly accepted as one of the causes of reduced crop productivity. This was attributed to increased spatial variability

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in crop stand, water, nutrient and root distribution (Hadas *et al*., 1986). Soil compaction due to machinery traffic causes substantial losses at the farm level but the extent of it depends on the tractor size used, machinery use intensity, weather conditions, and the type of crop grown (Lavoie *et al*., 1991). An experiment was conducted on a clay loam soil to study the effect of tillage machinery traffic on soil properties, corn root development and plant growth. A two-wheel driven tractor and a crawler tractor were used for the experiment. It was reported that tillage practices affected soil bulk density within the first 10 cm of tillage depth under both wheel and crawler tractors. The interaction of tractor and number of passes affected corn emergence. Poor emergence was reported when the soil was compacted with three passes of both wheel and crawler tractors. A long-term tillage effect was observed on dry matter yields and the differences were attributed to climatic variation over plant growth and root development. Plant height was found to be better in slightly compacted soils (Mari *et al*., 2006).

Organic materials (crop residues) have low density and when incorporated into the soil or left on the soil surface could cushion the effect of external load and will subsequently reduce the severity of compaction (Ohu *et al*., 2001). Gupta *et al*. (1987) stated that organic materials incorporated into the soil decompose over time to produce organic matter which can affect various soil physical properties like structure, hydraulic conductivity and aggregate stability. The authors further reported that a soil with high levels of organic matter has better structure and resists compaction more than soils with lower organic matter levels. Ohu *et al*. (1985) reported that the yield parameters of bush beans increased with increases in organic matter levels. The higher organic matter content was speculated to have improved the structure of the soil and the humic effect of organic matter might have supplied more nutrients to the crop, which resulted into higher yields. In a long-term application of green manures on soil properties and shoot and root growth of maize, Sangakkara *et al*. (2004) reported that application of green manures had beneficial effects on seedling growth of maize but not on germination or establishment.

Farmers in the semi-arid region of Nigeria have a variety of organic materials which could be added to the soil to cushion the effects of compaction and add nutrients to the soil. However, the use of organic materials especially crop residues is limited because some are used to feed livestock. Another limitation is that the organic materials differ in their ability to provide nutrients to crops and enhance soil quality and these differences relate to rates of decomposition and nutrient release rate and pattern (Kumar and Goh, 2002). Although there are several organic materials available to farmers in the semi-arid region of Nigeria, groundnut haulms has been found to be suitable for cushioning the effect of soil compaction (Ohu *et al*., 2001). The test soil in this study was vertisol. Vertisol was selected because it is the most difficult soil to manipulate and the most used for the cultivation of wheat, rice and sugarcane at different locations in the region. Although maize is widely grown under rainfed conditions in the region, there was no known comprehensive study on its cultivation in a vertisol. This was because the soil waterlogs after few rains and dries with cracks after the rains. This study was therefore designed to evaluate the effect of groundnut haulms and soil moisture content on the establishment and early growth of maize in a compacted vertisol.

MATERIALS AND METHODS

The soil used for this study was vertisol (Typic Pellustert). It was collected from the top 20 cm of the soil profile, 120 km away from the University of Maiduguri in Borno State. The sample was grounded to pass through a 2 mm sieve after which it was dried for two days. Particle size analysis was performed using the hydrometer method following the procedure of Lambe (1951) and the result was 65% clay, 24% silt and 11% sand. The organic matter content of the soil was estimated from the carbon content of the sample using the method of Walkley and Black (1934). The organic matter content of the soil was found to be 0.94%. This organic matter content was then increased by adding groundnut haulms. The groundnut haulms was also grounded to pass through a 2 mm sieve and was added to the soil to raise its organic matter content from 0.94 to 2, 4 and 6% on dry weight basis, respectively. The use of 2, 4 and 6% organic matter levels was based on the results reported by Ohu *et al*. (2001). In that report three organic materials (cow dung, chicken dung and groundnut haulms) were incorporated into different soils before load application. Results showed that groundnut haulms had the greatest effect in cushioning compaction in all the soils studied followed by cow dung and chicken dung and the minimum quantity for meaningful results was 2%.

The initial moisture content of the sieved soil sample was determined to be 8% using the oven-dry method. The liquid limit of the soil was 59.5% while the plastic limit was 33% and plasticity index was 26.5%. The soil sample was then divided into three batches. The first batch was mixed with 2% organic matter and the second and third with 4 and 6% organic matter, respectively. The moisture content of the soil-organic matter mixtures were raised to 20, 35 and 50%, respectively. These moisture content values were chosen according to the consistency limits of the soil. The soil-organic matter mixtures were packed into polythene bags and kept air-tight to prevent moisture loss and kept for three days for moisture equilibration. After that the soil samples were transferred into molds measuring 110 mm diameter and 180 mm height. Each of the soils in the molds was subjected to 0, 5, 10 and 15 blows of a standard Proctor hammer following the standard proctor compaction procedure (Lambe, 1951). After compaction, the dry bulk densities of the soils were determined using the method of Lambe (1951). Following the bulk density determination, the penetration resistances of the soils in the molds were determined using a hand pushed cone penetrometer following the American Society of Agricultural Engineers (1982) standard procedure. The penetrometer had a cone base diameter of 15 mm and cone angle of 30°. To determine the penetration resistances, the soils in the molds were compacted in three layers with the required number of hammer blows and thereafter measurements were taken at 5 cm depth. After taking the penetration resistances, the soils were discarded and fresh samples were compacted with the same number of hammer blows.

Maize (*Zea Mays*) seeds with high viability were then inserted into the molds at about 4-5 cm depths in all the 108 molds used. Three seeds were inserted into each mold with minimum soil disturbance. In order to enhance seedling emergence and to avoid water stress, 200 ml of water was added to each mold daily for 18 days. The molds were kept under direct sunlight during the day for about nine hours and taken to the laboratory at night for heat supply for emerging seedlings. Daily recording of emergence seedlings in each mold began 4 days after planting and final emergence counted was made on the 8th day. On the 10th day after planting, seedlings were thinned down to one per mold and daily recording of plant height began on the same day**.** Final measurement of plant height was made in the morning of the 21st day after planting and in the evening, the plants were harvested by removing the shoots with a sharp blade at 2 cm above the soil surface**.** The harvested plants were weighed immediately. The shoots were dried at 60ºC for 48 h and dry weights were determined. The soils in the molds were washed out gradually and the roots were removed, measured, weighed; and dried at 60ºC for 48 h and dry weights were determined as well. All the soil and crop parameters were measured in three replicates. The mean values of the soil and crop parameters were subjected to analysis of variance (ANOVA) to determine treatment effects. The ANOVA was done according to the procedure outlined by Gomez and Gomez (1984).

RESULTS

Figure 1a shows the effect of compaction on dry bulk density of the soil at different soil moisture contents and organic matter levels. Bulk density increased with increase in moisture content up to 35% and then decreased with further increase in moisture content (50%). This result is similar to that reported by Ohu *et al*. (1989. For all levels of moisture content, soil bulk density decreased with increase in organic matter level. The dry bulk density of the soil at 2% organic matter level, 20% soil moisture content and zero hammer blows was 1.17 Mg m^{-3}. This value increased to a maximum of 1.28 Mg m^{-3} at 10 hammer blows and then decreased to 1.13 Mg m^{-3} at 15 hammer blows. At 2% organic matter level, 20% soil moisture content and 10 hammer blows, dry bulk density of 1.28 Mg m^{-3} decreased to 1.16 Mg m^{-3} at 6% organic matter. The dry bulk density at 35% soil moisture content, 2% organic matter and 10 hammer blows was 1.38 Mgm^{-3}. This value decreased to1.26 Mg m^{-3} at 6% organic matter level. For 50% soil moisture content, 2% organic matter and 10 hammer blows, dry bulk density was 1.26 decreased to 1.14 Mg m^{-3} at 6% organic matter level. The mean values of soil bulk density were highest at 10 hammer blows, 2% organic matter and 35% soil moisture content. The 35% soil moisture content that recorded the highest values of soil bulk density could be regarded as the critical moisture content for compacting the soil-organic matter mixture. Soil bulk density was significantly affected by the interaction of soil moisture content and hammer blows at $P<0.05$. The interactions of organic matter level and moisture content or organic matter level and hammer blows were not statistically significant ($P<0.05$). Even though Ohu *et al*. (2001) reported that addition of organic matter could cushion the effect of compaction in this soil, it now appears that the extent of alleviation will depend on the moisture content of compaction.

The effect of compaction on penetration resistance at different levels of organic matter and moisture content levels is presented in Fig. 1b. For all compaction and moisture content levels, penetration resistance decreased with increase in organic matter level. Ohu *et al*. (2001) reported similar findings. At 20% soil moisture content, 2% organic matter and 10 hammer blows, penetration resistance was 6.46 MPa and this decreased to 5.51 MPa at 6% organic matter level. For 35% soil moisture content, 2% organic matter and zero hammer blows, penetration resistance was 5.18 MPa. This value of 5.18 MPa increased to a maximum of 6.65 MPa at 10 hammer blows and then decreased to 4.82 MPa at 15 hammer blows. The penetration resistance at 50% soil moisture content, 2% organic matter and zero hammer blows was 4.38 MPa and this increased to 6.28 MPa at 10 hammer blows and then decreased to 4.27 MPa at 15 hammer blows. The mean values of penetration resistance were also highest at 10 hammer blows, 2% organic matter and 35% soil moisture content. Penetration resistance was not significantly affected by the treatments at $P<0.05$.

Figure 1c presents the effects of soil compaction on emergence count of maize eight days after planting. At all moisture content and compaction levels, 4% organic matter gave the best seedling emergence. However, maximum level of compaction (15 hammer blows) gave the least emergence count at all moisture content and organic matter levels. This result is in line with that reported by Sangakkara *et al*. (2004) who reported that application of green manures only had beneficial effects on seedling growth of maize but not on germination or establishment. Emergence count at 20% soil moisture content, 2% organic matter and zero hammer blows was 76.8 and this increased to 88.7% at 5

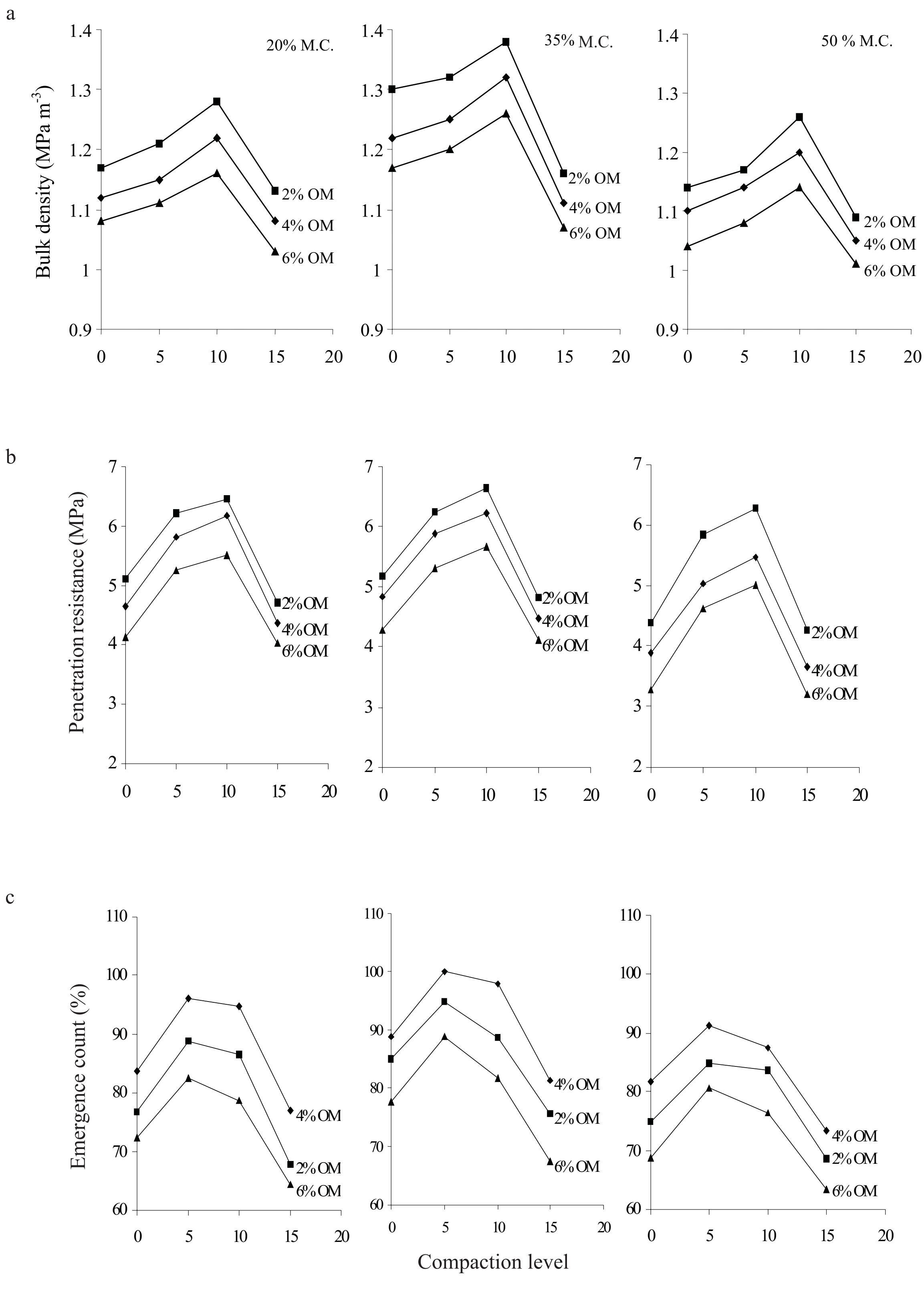

Fig. 1. Effect of compaction, organic matter (OM) and soil moisture content (MC) on: a – soil dry bulk density (Mg m^{-3}); b – penetration resistance (MPa); c – emergence count (%); d – plant height (cm); e – shoot moisture content (%); f – dry matter of shoot (g); g – dry matter of root (g); h – root length (cm).

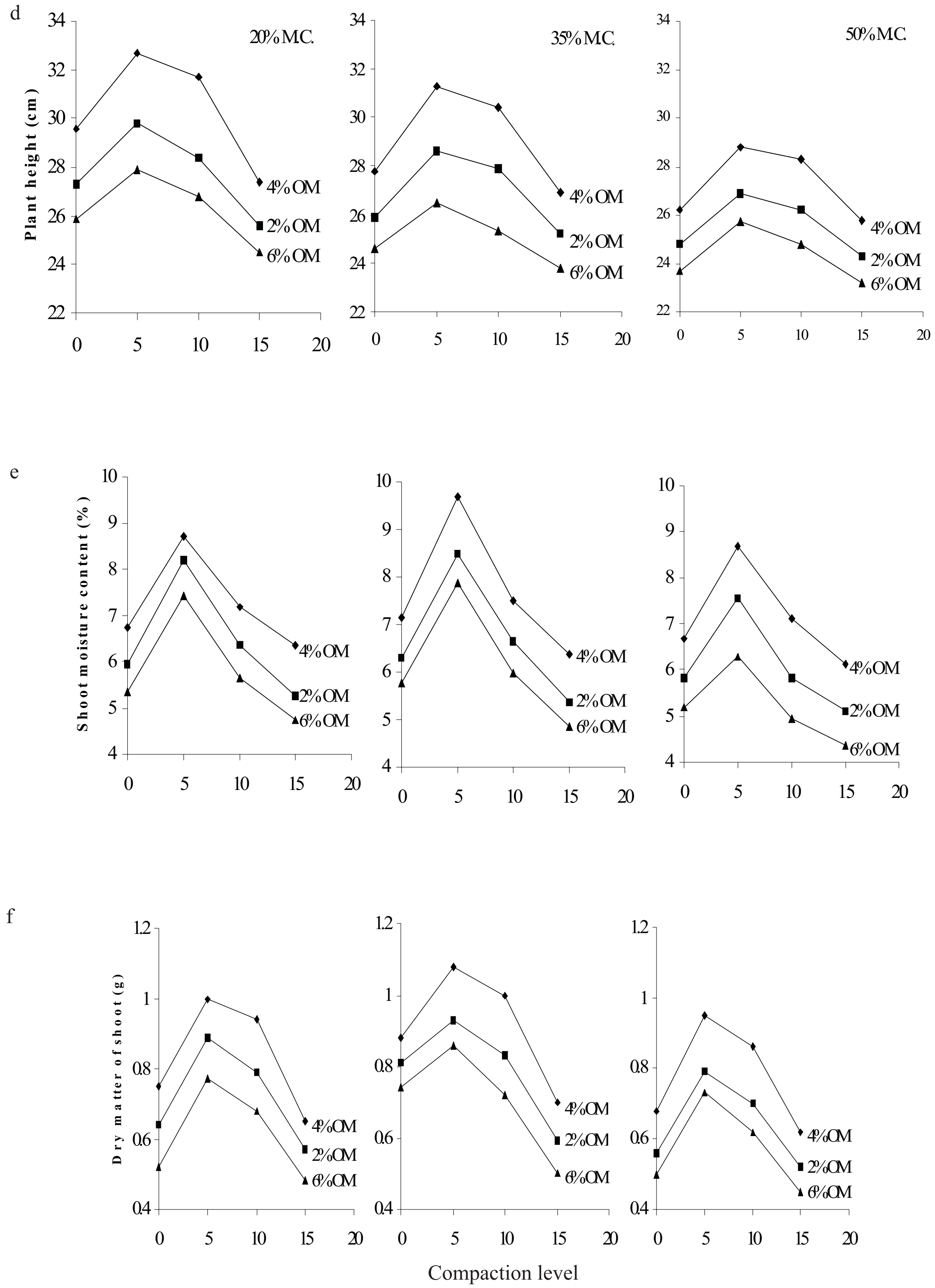

Fig. 1. Continuation.

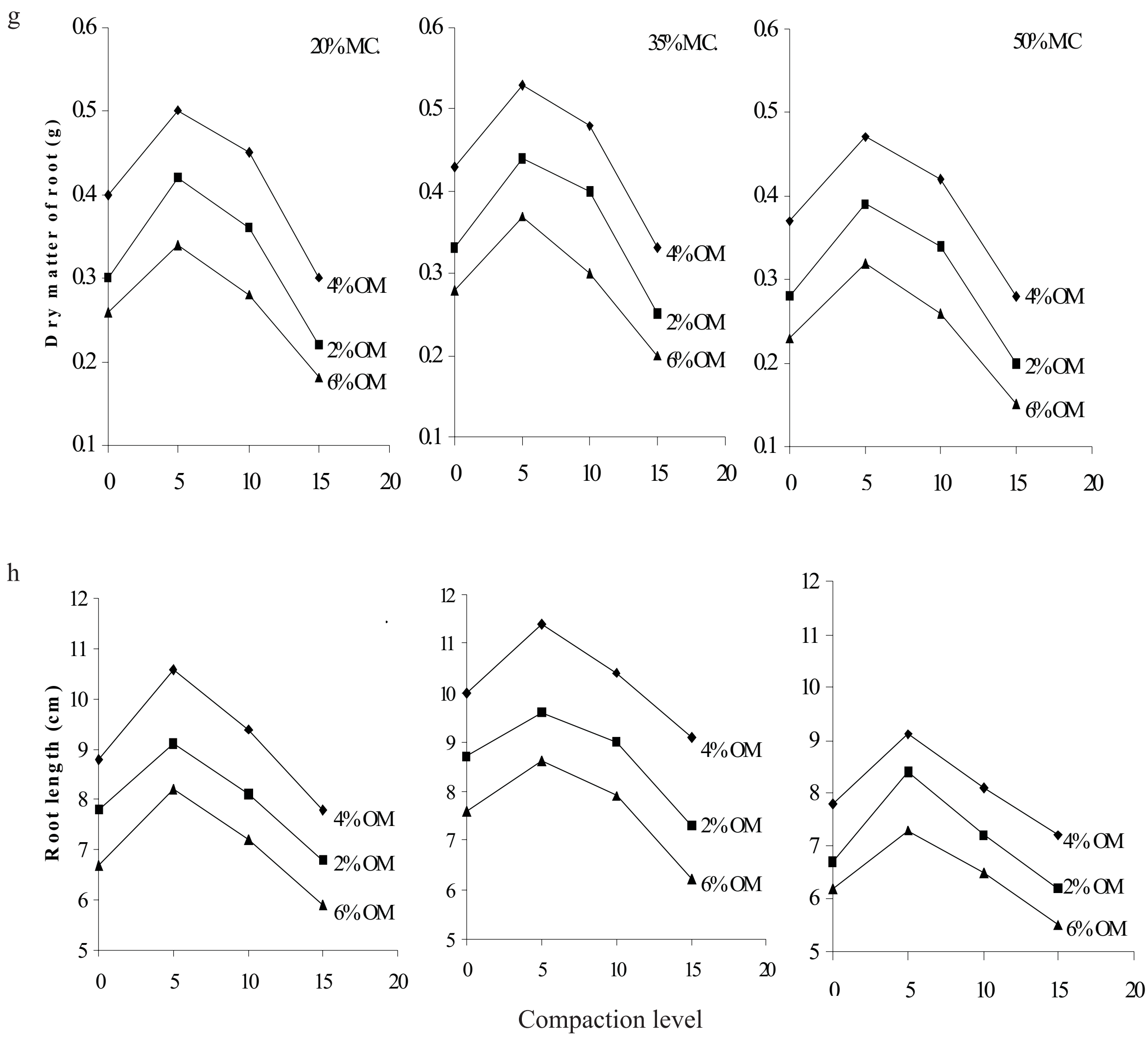

Fig. 1. Continuation.

hammer blows before decreasing to 67.8% at 15 hammer blows. For 35% soil moisture content, 2% organic matter and 5 hammer blows, emergence count was 94.8%. This value increased to 100% and then decreased to 88.9% at 4% and 6% organic matter levels, respectively. Emergence count at 50% moisture content, 2% organic matter and 5 hammer blows was 84.8% and this value increased to 91.3% before decreasing to 80.7 at 4 and 6% organic matter levels, respectively. The best seedling emergence counts at all hammer blows and organic matter levels were at 35% soil moisture content. Even with the incorporation of organic matter, zero compaction did not give the highest emergence count. This could be attributed to the loose nature of the soil which may have affected its water holding capacity and consequently, low uptake of nutrients. As compaction increased to 15 hammer blows, emergence count decreased to values lower than those obtained at zero hammer blows for all levels of the treatments. This result indicates that although organic matter incorporation has beneficial effects on emergence of maize in this soil, moisture content and hammer blows have dominant effect on the crop. Statistical analysis revealed that the interaction of soil moisture content and hammer blows have significant effect on emergence count at $P<0.05$.

The influences of soil moisture content, compaction and organic matter levels is presented in Fig. 1d. For all compaction and organic matter levels, plant height decreased with increase in moisture content. This indicates that maize growth is more influenced by soil moisture than organic matter (Sangakkara *et al.*, 2004). The best plant height was obtained at 4% organic matter level. At 20% soil moisture content, 2% organic matter and 5 hammer blows, plant height was 29.8 cm. This value increased to a maximum of 32.7 cm and then decreased to 27.9 cm at 4 and 6% organic matter levels, respectively. For 35% soil moisture content, 2% organic matter and 5 hammer blows, plant height was 28.6 cm and this value increased to 31.3 cm at 4% organic matter level and then decreased to 26.5 cm at 6% organic matter level. Plant height at 50% soil moisture content, 2% organic matter and 5 hammer blows was 26.9 cm. The result presented in Fig. 1d show that plants at zero hammer blows were taller than those at 15 hammer blows for all the treatments. This result confirms the harmful effect of excess compaction on crop growth and development. There was a statistically significant effect of the interaction between hammer blows and moisture content on plant height at $P<0.05$.

Figure 1e shows the relationship between compaction level and shoot moisture content at different soil moisture content and organic matter levels. Shoot moisture content increased with increase in moisture content up to 35% and then decreased with further increase in moisture content (50%). This result indicates that shoot moisture content of maize is not determined by soil moisture alone but by organic matter and compaction level. The highest shoot moisture content was recorded at 4% organic matter level. At 20% soil moisture content, 2% organic matter and 5 hammer blows, shoot moisture content was 8.2%. The moisture content increased from 8.2 to 8.7% and then decreased to 7.4 at 4 and 6% organic matter levels, respectively. For 35% soil moisture content, shoot moisture content was 7.2% at zero hammer blows and 4% organic matter levels. This moisture content increased to 9.7% and then decreased to 6.4% at 5 and 15 hammer blows, respectively. Shoot moisture content at 50% soil moisture content followed the same trend as those obtained at 20% and 35% soil moisture contents. At 50% soil moisture content, 4% organic matter level gave the highest shoot moisture content of 8.7% at 5 hammer blows. There was no significant ($P<0.5$) effect of the treatments on shoot moisture content.

The relationship between compaction level and dry matter of shoots at different soil moisture content and organic matter levels is presented in Fig. 1f. For all compaction levels, dry matter of shoot increased with increase in moisture content up to 35% and then decreased with further increase in moisture content (50%). The highest dry matter of shoots is recorded at 4% organic matter level. The dry matter of shoots at 20% soil moisture content, 2% organic matter and zero hammer blows was 0.64 g. This dry matter of 0.64 g increased to 0.89 g and then decreased to 0.57 g at 5 and 15 hammer blows, respectively. At 35% soil moisture content, 2% organic matter and 5 hammer blows, dry matter of shoots was 0.93 g and this increased to a maximum of 1.08 g and then decreased to 0.86 g at 4% and 6% organic matter levels, respectively. The highest amount of dry matter of shoots (0.95 g) was recorded at 50% soil moisture content, 5 hammer blows and 4% organic matter level and the least was 0.45 g at 6% organic matter and 15 hammer blows. Dry matter of shoot was not statistically significant at $P<0.05$.

Figure 1g presents the relationship between compaction level and dry matter of roots at different levels of soil moisture content and organic matter levels. Dry matter of roots followed the same trend as that of dry matter of shoots. The dry matter of roots at 20% soil moisture content, 2% organic matter and zero hammer blows was 0.30 g. This dry matter of 0.30 g increased to 0.42 g at 5 hammer blows and then decreased to 0.36 and 0.22 g at 10 and 15 hammer blows, respectively. The highest amount of dry matter of roots was 0.53 g and this was obtained at 35% soil moisture content, 4% organic matter and 5 hammer blows. The values of dry matter of roots at 50% soil moisture content followed the same pattern as at 20 and 35% soil moisture content levels. At 50% soil moisture content and 5 hammer blows, 4% organic matter gave the highest amount of 0.47 g and the least was 0.15 g at 6% organic matter and 15 hammer blows. Dry matter of root was not statistically ($P<0.05$) affected by the treatments or their interactions.

The influences of soil moisture content, compaction and organic matter levels are shown in Fig. 1h. For all moisture content and organic matter levels, 15 hammer blows gave the least root length. The best root length was recorded at 4% organic matter level. The high moisture content (50%) might have affected aeration which resulted in poor root growth. This result is in line with that reported by Lipiec and Hatano (2003). At 20% soil moisture content, 2% organic matter and zero hammer blows, root length was 6.8 cm. This value increased to 9.1 cm at 5 hammer blows and then decreased to 8.1 and 7.8 cm at 10 and 15 hammer blows, respectively. For 35% soil moisture content, 2% organic matter and 5 hammer blows, root length was 9.6 cm. This value increased to 11.4 cm at 4% organic matter level and then decreased to 8.6 cm at 6% organic matter level. Root length at 50% soil moisture content, 2% organic matter and zero hammer blows was 6.7 cm and then increased to 8.2 cm at 5 hammer blows before decreasing to 7.2 and 5.9 cm at 10 and 15 hammer blows, respectively. Root length of the crop was significantly ($P<0.05$) affected by the interaction between hammer blows and moisture content only.

CONCLUSIONS

1. Statistical analysis showed that non of the treatments considered had a significant effect on the soil or crop parameters but the interaction between hammer blows and soil moisture content significantly affected soil bulk density, emergence count, plant height, and root length at $P<0.05$.

2. At all moisture content levels and hammer blows, 6% organic matter level had the least mean values of bulk density and penetration resistance. This suggests that the incorporation of organic matter into vertisol could reduce the effect of compaction.

3. For all moisture content levels, the highest mean values of the crop parameters were recorded at 4% organic matter level and 5 hammer blows. This implies that although the organic matter has some influence on the crop parameters, there is a limit to the amount that could be added to improve yields.

4. Soil bulk density and penetration resistance gave their highest values at 35% soil moisture content. This could be regarded as the critical moisture content of the soil. But the results of the crop parameters showed that this moisture content (35%) favoured the crop. More research is needed with other crops to confirm this result.

5. There seems to be a good relationship between the maize heights, dry matter of shoots and roots and root length. The relationship between plant height and yield parameters and length of roots needs further investigation for other crops in a vertisol and other soils. This will help in predicting the yield of crops from their visual appearance.

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