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Compaction and Moisture suction effects on soil strength and crop emergence

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Abstract

Laboratory studies were conducted to determine the effects of four levels of soil compaction and five moisture suctions on the relationship between penetrometer soil strength and emergence of maize and cowpea seedlings for five constrasting soils of Western Nigeria. Compaction (bulk density) and moisture suction accounted for 75 – 88% of observed variation in soil strength and affected seedling emergence at specified soil strengths. The effect of compaction or moisture suction on the relation of seedling emergence to soil strength depended on soil and crop species. The rate of cowpea seedling emergence, which was about two-thirds that of maize, was more adversely affected by compaction than by high moisture suction. Cowpea emergence ceased when soil strengths exceeded 8 kg/cm^2 in the clay loam or 10 kg/cm^2 in the sandy clay loam and sandy loams, while corresponding values for maize were 14 kg/cm^2 for the clay loam and 18 kg/cm^2 for the other soils.

Introduction

The physical resisitance of soil to the growing seedling is a considerable factor in crop production as it affects the establishment of a uniform crop stand of a desired density and subsequent plant development. Soil parameters known to influence mechanical impedance include texture (Cassel *et al* 1978; Byrd and Cassel, 1980), bulk density and moiture content (Taylor and Gardner, 1963; Cassel and Nelson, 1979). Soil strength appears to be a critical impedance factor that is commonly used to relate mchanical impedance to seedling emergence. It is usually estimated by measuring penetration resistance of soil to a probe or penetrometer (Parker, Jr. and Taylor, 1965; Arndt, 1965; Farrell and Greacen, 1966).

The effect of soil compaction, which commonly results from cultural practices of crop production, on seedling emergence is noted through the changes in soil strength. Normally, soil strength and impedance of emerging seeeling increase with bulk density, the relationship is however not a simple one but depends on soil type and interactions of bulk density and soil water content (Taylor and Gardner, 1963; Hemsath and Mazurak, 1974). In the tropics, soils have predominantly weak structure that deteriorates rapidly as a result of cultivation or increased use of farm mechinery in cultural operations. This physical condition enhances compaction and poor physical regimes that may mechanically resist seedling emergence. Athough the effects of bulk density and moisture regime on soil strength have been reported for some Nigerian soils (Maurya and Lal 1979), comparatively little is known about the effects of soil physical characteristics on seedling emergence of the various crops (Falyai and Lal, 1979; Fapohunda, 1986) Knowledge of these is however required for management aimed at limiting soil impedance and ehancing crop production.

The objective of this study was to determine the relationship of compaction and matric suction to soil strenghth and seedling emergence under controlled laboratory conditons.

Materials and Methods

Five soils of widely contrasting pysical properties ranging from clay loam to loamy sand in texture were collected from the upper 15 cm layer under secondary bush regrowth in Nigeria for these studies. With the exception of Ogun soil, containing smectite, the soils contain predominantly kaolinite in the clay fraction. Table 1 summarizes the classification (Harpstead, 1973) and characteristics of the soils. Soil samples were air-dried and crushed to pass a 2-mm sieve. Soil cores 5.5 cm in diameter and 5 cm long were prepared by compressing (using an hydraulic press) a known weight of slightly moist soil to give bulk density (oven dry basis) values of 1.0, 1.2, 1.4 and 1.6 g/cm^3. The cores were then saturated with water and equilibrated on ceramic plates to matric suctions of 0.3, 0.5, 1.0, 3.0 and 5.0 bars. Three 2.5 cm deep holes were formed in the bottoms of the cores and seeds of maize (*Zea mays* L. var. 'FARZ 34') or cowpea (*Vigna unguiculata* S.Sp. unguiculata (L.) Walp var. 'Vita 5), partly-germinated by soaking in wet cheese cloth for 36 hours, were gently pressed into the holes. The holes were then filled back with soil and firmly pressed to provide good contact and footing for the seedlings. The surfaces of the cores were covered with lint and left in a humid chamber at 25^{0}C until emergence or 5 days after planting. Three cores were prepared for each combination of bulk density, suction and crop type.

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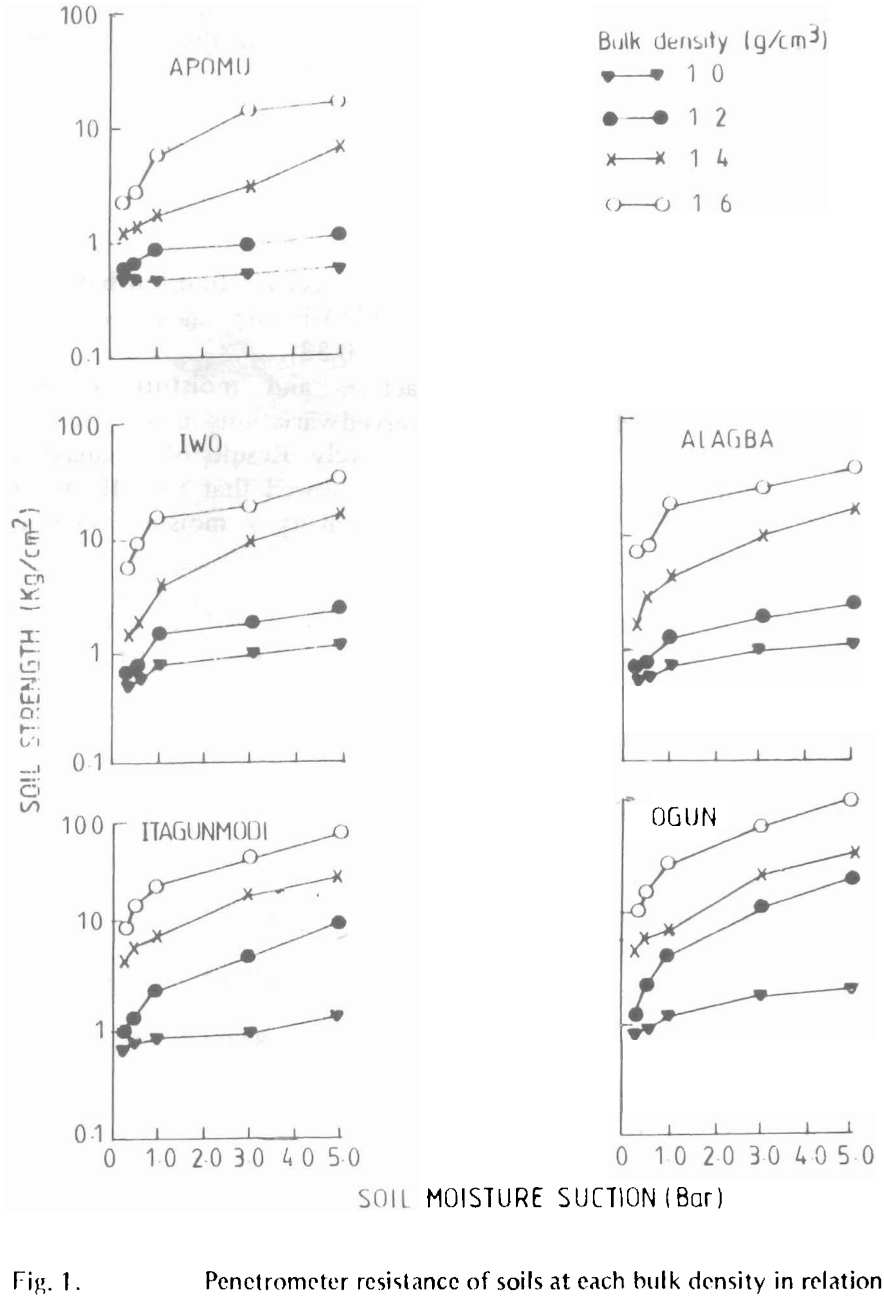

Fig. 1. Penetrometer resistance of soils at each bulk density in relation to soil moisture suction.

Considerable differences among soils were noted in the strength-suction–compaction relationships, reflecting textural disparity of the soils (Hemsath and Mazurak, 1974). While the loamy sand showed progressive increases in strength with increasing compaction or suction, a small compaction or increase in suction of the clay loams resulted in rapid increases in soil strength. The increased suction and compaction apparently resulted in greater cohesive forces between particles of the clay loams compared to the loamy sand because of higher clay contents of the former. This explains the observed closer relationship between soil strength and moisture suction (r = 0.56) in the sandy loams and clay loams compared to the loamy sand (r = 0.38).

The combined effect of compaction and moisture suction accounted for 75% and 88% of the observed variations in soil strength of the loamy sand and clay loams, respectively. Results of the anaylsis of variance for the experiment (Table 2) showed that the effects of compaction, mositure suction and bulk density x moisture suction interaction were significant at ⩽5% level.

TABLE 2: ANALYSIS OF VARIANGE SHOWING INFLUENCE OF DENSITY AND MOISTURE SUCTION ON SOIL STRENGTH.

Source of Variation	Degrees of freedom	Mean square
Bulk density (BD)	3	2259.7**
Suction (Suc)	4	860.5 **
Soils	4	420.9 *
BD x Suc.	12	283.0 **
Error (Main)	12	121.4
Error (sub-plot)	64	36.1

** F values are significant at the 1% level
* F values significant at the 5% level

Seedling elongation in the 2.5 cm soil layer was influenced by soil strength as shown in Figs. 2 and 3 for maize and cowpea. Generally, an increase in soil strengthdecreased elongation rateor increased time of emergence of seedling. An exception however occurred with maize in the loamy sand and the sandy loams where soil compression from a bulk density of 1.0 to 1.2 g/cm^3 with moisture suction at 0.3 bar improved seedling emergence, apparently due to increased soil-seedling contact. Maximum elongation rates for maize seedlings at these optimum treatment levels averaged 2.7 cm/day for the clay loam and 3.1 cm/day for the coarse textured soils (including the sandy clay laom). The coarse textured soils behaved alike in relation to maximum cowpea elongation rate (averaging 2.3 cm/day) which was higher than on the day loam soil (1.6 cm/day). On the average the time required for maize seedling to emerge from a 2.5 cm soil core was two-thirds and three-quarters that of cowpea in the clay loam and coarse textured soils, respectively.

Maize and cowpea seedlings differed markedly in their abilities to emerge from compressed soils. Critical soil strength where no emergence occurred, varied from 14 kg/cm^2 in the coarse textured soils to 18 kg/cm^2 in the clay loams for maize and correspondingly, 8 to 10 kg/cm^2 for cowpea. These values are considerably lower than actual measured seedling emergence forces reported in literature (Drew and Buchele, 1962; Clifford and Thran, 1969). The effect of soil strength on seedling emergence which accounted for 56% and 73% of observed variations in cowpea and maize emergence, respectively, was noted through the changes in soil bulk density and moisture suction. Decreased emergence of cowpea appeared to be more related to compaction ($r = -0.89$) than to high moisture suction ($r = -0.74$). Cowpea, like other dicotyledons as reported by Parker and Taylor (1965) emerge by shearing and lifting parts of the soil rather than "worm" its way through the soil like maize, thereby requiring considerably greater force to emerge in compact or high-strength soils such as clay loams. Bulk density and mositure suction levels associated with critical soil strength values are 1.4 g/cm^3 and 1.0 or 3.0 bars, respectively.

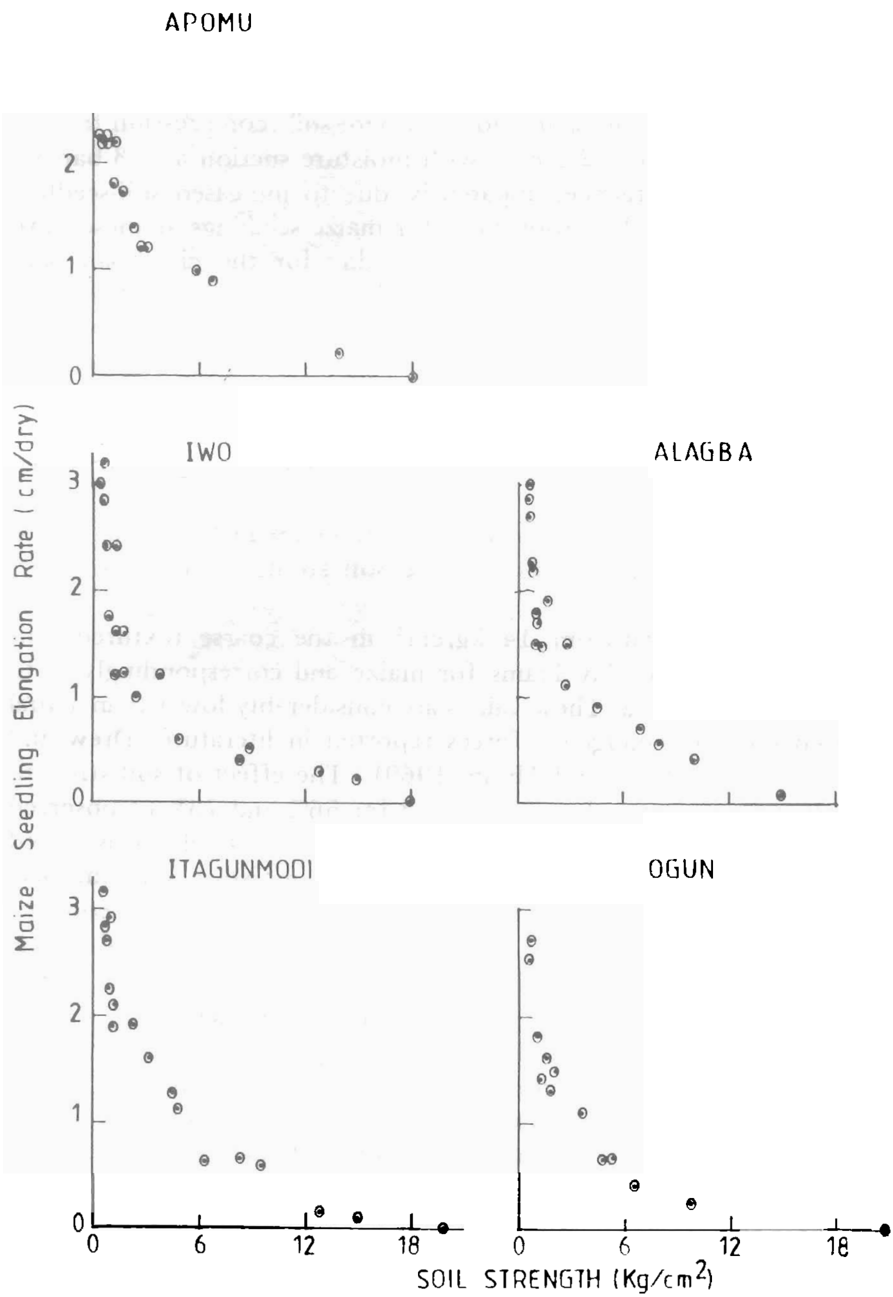

Fig. 2. — Relationship between mean maize seedling growth rate and soil strength for different soils.

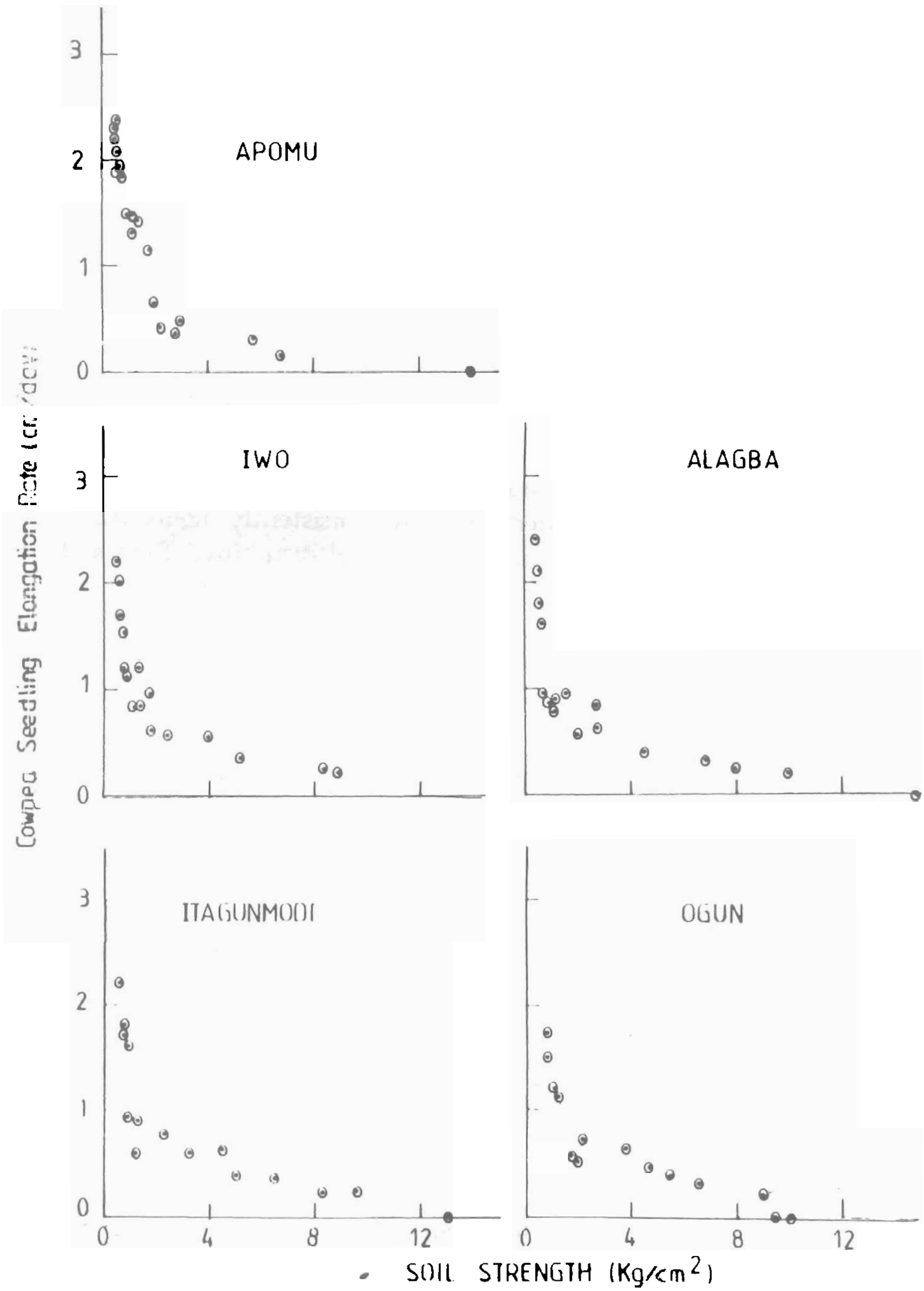

Fig. 3. Relationship between cowpea seedling growth rate and soil strength for different soils.

Summary and Conclusions

The general relation of seedling emergence to bulk density and moisture suction in this study was partially attributed to soil strength; only 56% and 73% of observed variations in cowpea and maize seedling emergence were attributed to soil strength. This result implies that some other factors unexplained by physical resistance constitute important sources of variation in seedling emergence. For example, seedling pressure, guttation and aeration have been suggested to influence seedling emergence of some crops (Hanks and Thorpe, 1957). Among soils used in this study, airfilled porosity was lowest in the clay loams, raning from 10% to 19% at highest and lowest bulk density – suction treatment levels, respectively. It is unlikely that the oxygen level would be low enough during the experiemnt to inhibit seedling growth.

The ranges of soil bulk density and moisture regimes of this experiment are representative of those commonly encountered in soils under bush fallow and different stages of cultivation across Western Nigeria. Although results of remolded cores are consistently higher than in-situ seedling impedance determinations on well-structured field soils, the results of this study however are useful in indicating what level of compaction and water suction can be expected to adversely affect seedling emergence in these and similar soils. The knowledge of this is required in management aimed at reducing soil impedance to emerging seedling and enhancing crop yield.

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