Soil physical and hydrological properties modifications under 
*Arachis* species in Ibadan, southwestern Nigeria

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Abstract

Lack of conservation of soil moisture is one of the major limiting factors to crop production. Improvement of soil physical properties could enhance soil moisture conservation, improve crop productivity and reduce food insecurity in sub-Sahara Africa. A field study was carried out to determine the effects of three plant densities (33333, 66667 and 83333) per hectare on soil properties and water loss through evaporation from soils under two cultivars of *Arachis hypogaea* L. (SAMNUT 10 and SAMNUT 21) and *Arachis pintoi* (PINTOI) in Ibadan, southwestern Nigeria. The experiment was set in a split plot in randomised complete block design with *Arachis* varieties as the main plot and plant densities as sub-plot with three replications. Data were collected on daily soil water evaporation, bulk density, saturated hydraulic conductivity, particle size, total porosity and permeability. The soil was loamy-sand. Marked reductions in soil water evaporation were observed in surfaces under *Arachis* varieties compared to bare soil. Reductions in soil water evaporation were 44.5% under SAMNUT 21, 41.1% under PINTOI and 34.7% under SAMNUT 10. There was significant (p = 0.05) improvement on soil structure and hydraulic conductivity under *Arachis* varieties. Plant density of 66667 ha\(^{-1}\) had the best positive effect on the improvement of soil physical structures. The cultivation of SAMNUT 21 at plant density of 66667 ha\(^{-1}\) and PINTOI at 83333 ha\(^{-1}\) along with other measures of sustainable soil water conservation are recommended.

Key words: *Arachis* species, plant densities, evaporation, soil hydrological properties, food insecurity.

Introduction

Soil and water are basic, vital and essential resources for sustainable agriculture. Hence, the knowledge of soil properties is essential and its proper management is a major factor to crop productivity and sustainability (Anikwe and Ubochi, 2007; Franzluebbers, 2002). The hydrological conditions and related physical properties of the soil are important factors in crop growth, and should be considered when selecting measures for different sites for crop production and soil-water conservation (Lundin, 1982; Nyberg, 1995). This implies that these resources should be utilised in ways that ensure little or no damage whilst guaranteeing their continuous usage while still providing food and fibre for the teeming population.

Several methods have been recommended for conservation of soil. These include the planting of cover crops such as groundnut, peanut, vetiver grass to reduce erosion, zero tillage and minimum tillage, use of plant (crop) residues, green manures, animal manure, mulches and household waste. Farmers have adopted some of these practices but have not been able to sustain them because of affordability and availability of the inputs. A review of technology that is acceptable to resource-poor farmers (Hocking, 1993), involves the combination of practices into a farming system that considers physical factors such as soil and climate, available resource input, especially cash and labour. Thus, cover crops due to its low input and long-term benefits has widely been accepted and occasionally used by farmers at all levels (Smith *et al*., 1987).

Over two-thirds of the global crop production occurs in rainfed regions where rainfall is erratic and insufficient (Wright and Nageswararao, 1994). Evaporation, which is often the largest component of substantial water loss in soil poses severe consequential implications on crop production since surface soil-water content is important in crop production. However, with series of work, cover crops had been
used as mulch which are planted to manage soil water, soil physical properties and soil fertility; and for the suppression of weeds, pests and diseases (Lu et al., 2000). Thus, the utilisation of the stored moisture will depend on the favourable soil physical environment which can be achieved by maintaining desired soil surface conditions through the use of cover crop. This plays an important role in preventing loss of water by evaporation which is beneficial to crop growth. If some of this unproductive loss of water could be retained in soil and used as transpiration, yields could be increased without the use of supplemental irrigation.

This trial aimed at reducing soil water loss using different *Arachis* spp. and *Arachis* densities as a way of soil moisture conservation and to determine their effect on soil physical and hydrological properties.

**Materials and methods**

**Study area**

The experiment was carried out at the University of Ibadan (7° 26’.37” N; 3° 54’.08” E) at an altitude of 233 m, Oyo State, Nigeria, between August and November 2011. It is at the edge of the rain forest belt of Nigeria and the soil type is Alfisol derived from basement complex (Iwo Series). The area lays in the sub-humid tropics. The climate is divided into wet season (April-October) and dry season (November-March). The mean annual rainfall is 1200-1300 mm while monthly variation in temperature is between 23 and 31°C.

**Experimental materials**

The test crop used in the trial was groundnut (*Arachis hypogaea*) (varieties SAMNUT 10 and SAMNUT 21) and *Arachis pintoi*. Microlysimeters were used to determine daily evaporation.

Cover crops can be defined as close-growing crops that provide soil protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards (SSSA, 1997). It is planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in agroecosystems (Lu et al., 2000). Cover crops are of interest in sustainable agriculture as many of them improve the sustainability of agroecosystem attributes and may also indirectly improve qualities of neighbouring natural ecosystems. Leguminous species are the most common cover crops planted in soil conservation practices, among which is *Arachis* spp., to which *A. hypogaea* and newly introduced *A. pintoi* belongs.

The seeds varieties of SAMNUT 10 and SAMNUT 21 were collected from the Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, Kaduna State, Nigeria. Stem cuttings of *Arachis pintoi* were collected from Department of Agronomy Garden, University of Ibadan.

Brief descriptions of the varieties as provide by the IAR, ABU, Zaria are given below:

**SAMNUT 10**: This Groundnut variety is adapted to Guinea and Forest Savanna of Nigeria. It is late maturing variety with duration of 135-150 days. The colour of seed is variegated (tan and white) with a potential yield of 2000 kg ha⁻¹.

**SAMNUT 21**: This is adapted to Guinea and Sudan Savanna of Nigeria. It is medium in maturity with duration of 110-120 days. The seed colour is variegated (tan and white). It can yield of 2000 kg ha⁻¹.

**Arachis pintoi**. Pinto peanut; perennial peanut is a forage plant native to *Cerrado* vegetation in Brazil. *A. pintoi* is a perennial, crawling herb with shallow root system, long flowering duration, many branches and rooting in every node. This wild perennial relative of the groundnut has been of increasing importance to pasture improvement in the tropics. It is suitable for growth in tropical or sub-tropical regions. Its height of straw layer is 15-30 cm. Owing to its merits of acid-tolerance, barren land-tolerance, stoloniferous growth habit and drought-tolerance; it has been widely cultivated for water-soil conversation, soil fertility enhancement and as an ornamental turf grass (Huang Yi-bin et al., 2004).
**Microlysimeter.** Also called evaporimeter were made of PolyVinyl Chloride (PVC) pipe of 10 mm thickness and 10 cm diameter cut into 10 cm length. A perforated metal base plate were used to cover their bottom to hold the soil in place and to allow free drainage.

**Experimental design and treatments**

The experimental design used was split plot in a randomised complete block design with three replications. *Arachis* varieties were the main plot and plant densities the sub-plot. The three plant densities were 66667 ha⁻¹ at 75 × 20 cm, 33333 ha⁻¹ at 75 × 40 cm, and 83333 ha⁻¹ at 60 × 20 cm. Dimension of each main plot were adopted as 14 × 5 m and subplot as 5 × 4 m. After land clearing, ridges were made using the specified inter-row spacing; seeds of *A. hypogaea* and stem cuttings of *A. pintoi* were planted manually using the specified intra-row spacing.

**Data collection and analysis**

**Evaporation measurement.** After crop establishment at 52 days after planting (DAP) when canopies had fully developed, microlysimeter tubes were inserted into the soil under a representative canopy, removed with the soil intact; they were capped at their bottom with a metal base plate and then placed back into the holes. This was done in each plot and on a bare soil so as to measure daily evaporation under cropped and bare soil. Lysimeter measurements were obtained until senescence. Readings were recorded at 24-h intervals using an electronic weighing balance (sensitivity at one gramme). Microlysimeters were extracted from the soil profile immediately after rain; the soils in the tubes are poured off so as to obtain a new representative drained soil sample and its replacement within 4 h.

**Soil sampling and analysis.** Soil sampling and analysis were carried out before land preparation and after harvest to determine physical and hydrological properties using a soil auger and a 100 cm³ soil cores. Bulk density was determined from oven dried undisturbed cores as mass per volume of oven-dried soils, saturated hydraulic conductivity was determined using constant head of water above undisturbed core and particle size distribution was determined using hydrometer method. Total porosity was calculated from the parameters of bulk density and particle density (assumed value of 2.65 Mg m⁻³) while saturation percent was determined from total porosity and permeability from saturated hydraulic conductivity.

Statistical analysis was done applying the analysis of variance. Least significant difference was used to separate means at 5 % level of significance.

**Results and discussion**

**Particle size distribution**

The particle size distribution of the experimental site before planting showed that the soil texture is loamy sand (Table 1). The soil is principally sandy; with sand accounting for more than 75% of the inorganic mineral fragment in the soil. The corresponding soil bulk density was 1.36 Mg m⁻³, soil porosity obtained was 54.8 %. Hydraulic conductivity was 1.05 cm min⁻¹ while permeability was 1.6 x 10⁻¹¹ m².

Soil texture and structure is important in describing the health of agricultural soils and it is important for water infiltration, aeration and plant root development (Fageria, 2002).

**Sand (2-0.05 mm in diameter).** *Arachis spp.* did not significantly influence sand particles although, a reduction was observed under each of the variety used when comparing initial values to post harvest values (Table 2).

Sand fraction were significantly (P > 0.01) varied under *Arachis* densities. Plant density of 66667 ha⁻¹ improved soil condition by reducing the sand content when compared to the initial status. Whereas, increased sand fraction were observed under densities 33333 and 83333 ha⁻¹.
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The magnitude of change indicate that sand particles in respect to initial status of soil under Arachis varieties improved soil condition with SAMNUT 10 performing best (Table 3).

Silt (0.002–0.05 mm in diameter). Arachis spp. did not significantly influence silt content of the soil (Table 2), but there was reduction in silt content when compared to initial soil status. There was more reduction in silt content in SAMNUT 21 than in SAMNUT 10.

### Table 1: Soil Physical and hydrological properties of the site prior to planting

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (g kg⁻¹)</td>
<td>823.4</td>
</tr>
<tr>
<td>Silt (g kg⁻¹)</td>
<td>110.2</td>
</tr>
<tr>
<td>Clay (g kg⁻¹)</td>
<td>66.4</td>
</tr>
<tr>
<td>Textural Class</td>
<td>loamy sand</td>
</tr>
<tr>
<td>Bulk density (Mg m⁻³)</td>
<td>1.36</td>
</tr>
<tr>
<td>Total porosity (%)</td>
<td>54.8</td>
</tr>
<tr>
<td>Sat. hyd. Con. (cm min⁻¹)</td>
<td>1.05</td>
</tr>
<tr>
<td>Permeability (m²)</td>
<td>1.6 x 10⁻¹¹</td>
</tr>
</tbody>
</table>

### Table 2: Post-planting soil physical and hydrological properties at organo-mineral: Fertiliser Research Plant Site along Barth road, University of Ibadan in 2011

<table>
<thead>
<tr>
<th>Sand (g kg⁻¹)</th>
<th>Silt (g kg⁻¹)</th>
<th>Clay (g kg⁻¹)</th>
<th>Hydraulic conductivity (cm min⁻¹)</th>
<th>Permeability (m²)</th>
<th>Total porosity (%)</th>
<th>Bulk density (Mg m⁻³)</th>
<th>Saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PINTOI</td>
<td>814.9</td>
<td>105.8</td>
<td>79.2a</td>
<td>1.61a</td>
<td>2.32E⁻¹¹</td>
<td>53.94</td>
<td>1.38</td>
</tr>
<tr>
<td>SAMNUT 10</td>
<td>813.3</td>
<td>109.1</td>
<td>77.6a</td>
<td>0.83b</td>
<td>1.62E⁻¹¹</td>
<td>54.29</td>
<td>1.42</td>
</tr>
<tr>
<td>SAMNUT 21</td>
<td>818.4</td>
<td>104.0</td>
<td>77.6a</td>
<td>0.79b</td>
<td>1.59E⁻¹¹</td>
<td>55.71</td>
<td>1.44</td>
</tr>
<tr>
<td>LSD</td>
<td>NS</td>
<td>NS</td>
<td>8.88*</td>
<td>0.401**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Initial</td>
<td>823.4a</td>
<td>110.2b</td>
<td>66.4</td>
<td>1.05</td>
<td>1.63E⁻¹¹</td>
<td>54.82</td>
<td>1.36</td>
</tr>
<tr>
<td>(60 × 20) cm²</td>
<td>831.2a</td>
<td>94.9b</td>
<td>73.8</td>
<td>1.13</td>
<td>2.12E⁻¹¹</td>
<td>54.85</td>
<td>1.41</td>
</tr>
<tr>
<td>(75 × 20) cm²</td>
<td>793.3b</td>
<td>131.6a</td>
<td>75.1</td>
<td>1.24</td>
<td>2.02E⁻¹¹</td>
<td>55.46</td>
<td>1.47</td>
</tr>
<tr>
<td>(75 × 40) cm²</td>
<td>828a</td>
<td>95.4b</td>
<td>76.6</td>
<td>0.85</td>
<td>1.23E⁻¹¹</td>
<td>53.76</td>
<td>1.36</td>
</tr>
<tr>
<td>LSD</td>
<td>21.29**</td>
<td>21.14**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>V x S(LSD)</td>
<td>42.57**</td>
<td>42.28**</td>
<td>NS</td>
<td>0.69**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

V x S = variety by spacing interaction. Values followed by the same letters are not significantly different from each other *= (p<0.05); **= (p<0.01); ***= (p<0.001); NS= Not Significant. E = 10⁻¹¹
Silt content varied significantly (P < 0.01) under *Arachis* densities (Table 2). *Arachis* density of 66667 ha\(^{-1}\) increased the silt content with at about 20% (Table 3). The increase in silt content is attributed to the development of dense cover and maximum utilisation of space which helps to suppress soil erosion.

*Arachis* spp. significantly (p < 0.05) influenced the clay content of the soil when compared to initial soil status (Table 2). There was increase in clay content under all the three varieties with PINTOI showing greater influence on the soil clay content by increasing the clay content by about 20% in the initial soil status. Varieties SAMNUT 21 and SAMNUT 10) increased clay content by about 17%.

Although *Arachis* densities of 33333 ha\(^{-1}\) increased the clay content of the soil by 74%, 66667 ha\(^{-1}\) by 75% and 83333 ha\(^{-1}\) 76% (Table 3), there were no significant influence (Table 2).

The change in clay content of soil at harvest with respect to initial soil status showed that all treatments resulted in the increase of the clay content (Table 3). This result indicates that all treatment imposed on the trial reduce erosion by wind dispersion and water dispersion by reducing impact effect of rain drop on soil surface through its canopy architecture and also reduce dislodging of clay particles through efficient rooting system. This implies that the increase in clay content of the soil will increase water holding capacity of the soil. This finding agree with that reported by Aiyelari and oshunsanya (2008) who stated that any practice that increases clay particles of a soil will enhance water retention of the soil.

**Hydraulic conductivity (Ks) and permeability (K).** *Arachis* spp. significantly (p < 0.01) influenced the hydraulic conductivity of the soil (Table 2). However, only plot planted with PINTOI improved saturated hydraulic conductivity of the soil at 53%, while reduced saturated hydraulic conductivity were observed under groundnut plot. *Arachis* spp. did not significantly influence permeability, although the PINTOI plots had an improvement of of 42%, while reduced permeability were observed under groundnut plots.

On the other hand, both saturated hydraulic conductivity and intrinsic permeability of the soil were not significantly influenced by Arachis densities (Table 2). 66667 plants ha\(^{-1}\) and 83333 plants ha\(^{-1}\) improved soil condition by increasing saturated hydraulic conductivity and permeability with a magnitude of 7%, 18% and 30%, 24% respectively.

Plots planted with PINTOI and those under 66667 and 83333 ha\(^{-1}\) treatments improved the soil condition in initial soil status. The result obtained supports series of research which indicates that cover

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**Table 3:** The magnitude of change (%) in soil properties under variety and plant spacing with respect to soil initial status

<table>
<thead>
<tr>
<th></th>
<th>Sand (g kg(^{-1}))</th>
<th>Silt (g kg(^{-1}))</th>
<th>Clay (g kg(^{-1}))</th>
<th>Hydr. conduc (cm min(^{-1}))</th>
<th>Permeability (m(^{-2}))</th>
<th>Total porosity (%)</th>
<th>Bulk density (Mg m(^{-3}))</th>
<th>Saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PINTOI</td>
<td>-1.03</td>
<td>-3.99</td>
<td>19.28</td>
<td>52.85</td>
<td>42.33</td>
<td>-1.61</td>
<td>-1.47</td>
<td>-1.8</td>
</tr>
<tr>
<td>SAMNUT 10</td>
<td>-1.23</td>
<td>-1.00</td>
<td>16.87</td>
<td>-21.10</td>
<td>-0.62</td>
<td>-0.97</td>
<td>-4.41</td>
<td>-1.8</td>
</tr>
<tr>
<td>SAMNUT 21</td>
<td>-0.61</td>
<td>-5.63</td>
<td>16.87</td>
<td>-24.54</td>
<td>-2.45</td>
<td>1.62</td>
<td>-5.88</td>
<td>1.82</td>
</tr>
<tr>
<td>(60 x 20) cm(^2)</td>
<td>0.95</td>
<td>-13.88</td>
<td>11.15</td>
<td>7.22</td>
<td>30.06</td>
<td>0.06</td>
<td>-3.68</td>
<td>0.00</td>
</tr>
<tr>
<td>(75 x 20) cm(^2)</td>
<td>-3.66</td>
<td>19.42</td>
<td>13.10</td>
<td>17.59</td>
<td>23.93</td>
<td>1.17</td>
<td>-8.09</td>
<td>1.82</td>
</tr>
<tr>
<td>(75 x 40) cm(^2)</td>
<td>0.56</td>
<td>-13.43</td>
<td>15.36</td>
<td>-19.39</td>
<td>-24.54</td>
<td>-1.93</td>
<td>0.00</td>
<td>-1.8</td>
</tr>
<tr>
<td>Soil condition</td>
<td>better</td>
<td>worse</td>
<td>Worse</td>
<td>worse</td>
<td>Worse</td>
<td>better</td>
<td>worse</td>
<td>Better</td>
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<tr>
<td>Soil condition</td>
<td>worse</td>
<td>better</td>
<td>Better</td>
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<td>Better</td>
<td>worse</td>
<td>better</td>
<td>Worse</td>
</tr>
</tbody>
</table>
crops are good soil conditioners because their vigorous, shallow and fibrous root systems loosen the soil and improve soil tilth.

Improvement in soil hydraulic conductivity and infiltration by modifying soil structure, aggregate stability and macro pores using cover crop have been reported by Murphy et al. (1993) and Kumar and Goh (2000).

Total porosity, saturation percent and bulk density. Although there were changes in all the three parameters, *Arachis* spp and *Arachis* densities did not significantly influence any of these parameters. Total porosity was considered to be improved under PINTOI, SAMNUT10 and density of 33333 ha\(^{-1}\) since reduction in porosity obtained under these three factors varied their values towards 50%. This indicates equal proportion of pores (macro and micro) in soils.

The result observed for saturation percent also follow the same trend as total porosity, this indicate that degree of wetness of the soil would permit optimal aeration of the soil.

The bulk density which is the measure of soil weight varied under all the treatments, except under *Arachis* density of 83333 ha\(^{-1}\) which remained unchanged.

Effect of different *Arachis* varieties and *Arachis* densities on soil evaporation: conserving soil moisture. The result from soil evaporation study under *Arachis* canopy and bare soil (Figure 1) shows that soil moisture depletion achieved a significant decrease under cropped land than in open bare soil, particularly under SAMNUT 21. It conserved soil moisture by about 44.5%, followed by PINTOI with 41.1% and SAMNUT 10 at 34.7%. This is as a result of several reasons, amongst is varietal differences, changing evaporative demands of the atmosphere especially in the controlling factor of insolation, and heterogeneity in soil characteristics. Conserving soil moisture with cover crop residues is reported by among others Smith et al. (1987) and Sustainable Agriculture Network (1998).

![Cumulative evaporation under *Arachis* varieties as compared to bare soil](image)

**Figure 1:** Cumulative evaporation under *Arachis* varieties as compared to bare soil

Evaporation under canopy at different *Arachis* densities shows that plant density of 66667 ha\(^{-1}\) performed best in reducing soil evaporation followed by the 83333 ha\(^{-1}\) and the 33333 ha\(^{-1}\).
When residues are left on soils, it improves infiltration of rain water and also reduce evaporative losses, resulting in less moisture stress during drought periods (Smith et al., 1987). The greatest differences in water contents between mulched and bare soils can be expected during short dry periods of 7-14 days (Smith et al., 1987).

**Combine effect of variety and plant spacing on soil properties.** Interactive effect of variety and *Arachis* densities significantly ($p < 0.01$) influenced sand fraction, silt content and saturated hydraulic conductivity of the soil while other parameters were not significantly varied (Table 2). These interactions show how well a variety best suit or perform at different plant spacing.

Combined effect of variety and *Arachis* densities were observed on sand fraction of the soil (Figure 3). PINTOI at 66667 ha$^{-1}$ and SAMNUT10 at 83333 ha$^{-1}$ improved the soil significantly ($p < 0.01$) by reducing sand fraction. This implies that PINTOI at a spacing of $75 \times 20$ cm and SAMNUT10 at a spacing of $60 \times 20$ cm enhance soil sustainability through sand reduction.
Figure 3: Interactive effect of variety and spacing on sand fraction after harvest

Interactive effect of variety and *Arachis* densities on silt fraction of the soil follows the same trend as in sand fraction (Figure 4). This result indicates PINTOI at 66667 ha\(^{-1}\), SAMNUT 10 at 83333 ha\(^{-1}\) and SAMNUT 21 at 66667 ha\(^{-1}\) improved the soil significantly (p < 0.01) increasing silt content of soil.

Figure 4: Interactive effect of variety and spacing on silt fraction after harvest

Interactive effect of variety and spacing on hydraulic conductivity of the soil (Figure 5). PINTOI at a spacing 75 × 20 cm had the best improvement on hydraulic conductivity while spacing 75 × 40 cm improved hydraulic conductivity of the variety planted.

Figure 5: Interactive effect of variety and spacing on hydraulic conductivity after harvest

Conclusion
Arachis spp. and densities used reduced water evaporation from the soil, which indicates that more water is made available for efficient crop production. Arachis spp. (with PINTOI performing best) improved the soil properties significantly in clay content, porosity, permeability and hydraulic conductivity. These properties have close relationship with water holding capacity of the soil and therefore, will increase water availability and distribution in soil. SAMNUT 21 performed best in soil water conservation.

Recommendations

It is therefore recommended that for optimum performance, PINTOI should be spaced at 60 × 20 cm (83333 ha⁻¹), SAMNUT21 at 75 × 40 cm (33333 ha⁻¹) and SAMNUT 10 at 75 × 20 cm (66667 ha⁻¹). Planting cover crops before or between main crops as well as between trees or shrubs of plantation crops can improve soil physical as well as chemical, and biological properties and consequently lead to improved soil health and yield of principal crops.

References


