

**EFFECTS OF WATERING INTERVAL, PLANTING  
DEPTH AND SOIL CRUSTING ON EMERGENCE  
AND SEEDLING ESTABLISHMENT OF SORGHUM  
[*Sorghum bicolor* (L.) Moench].**

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**LUSAKA**

**2000.**

## DECLARATION

I, Napo Emmanuel Ntlou hereby declare that this dissertation represents my own work and that it has not been previously submitted for a degree at this or any other university.

.....  
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**Date**

## APPROVAL

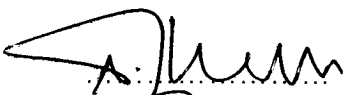
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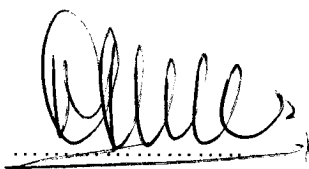
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## **DEDICATION**

To my wife, `Mamoshoanae and son, Motseko for their inspiration.

I love you!

## **ABSTRACT**

A study was conducted in the glasshouse to investigate the effects of soil type, watering interval, planting depth, and crust formation on emergence and seedling establishment of sorghum. Three separate pot experiments were conducted using three soil types and sorghum as a test crop. Various treatment combinations of soil type/watering interval, soil type/planting depth and soil type/water drop size delivered from a rainfall simulator were evaluated. Following the addition of water through the rainfall simulator, soil samples were prepared into thin sections that were examined under a microscope to determine the impact of water drops on the soil. Sorghum emergence, shoot height and shoot dry matter, and crust strengths of the soils were measured. Sorghum emergence was measured for 15 days while shoot height and shoot dry weight were measured at 28 days after planting.

Watering intervals had no significant effect on seedling emergence. Increasing watering interval from 2 days to 8 days reduced shoot height and shoot dry weight on all three soils. Shoot height and shoot dry weight from clay loam soil was significantly ( $P \leq 0.01$ ) higher than from both the sand soil and the sandy loam soil. The effect of planting depth on seedling emergence was highly significant ( $P \leq 0.01$ ). The seedling emergence percentage at 15 days after planting (DAP) was significantly higher at the shallower planting depth of 3 cm (98%) than at the depths of 6 cm (64%) and 9 cm (13%).

Shoot height and shoot dry mass were significantly ( $P \leq 0.01$ ) reduced when seeds were planted any deeper than 3 cm. The effect of crusting on emergence and seedling establishment varied significantly ( $P \leq 0.01$ ) with soil type. Seedling emergence was 83% from sandy loam, 81% in sand and with the least from clay loam (52%) at 15 DAP. The crust strength varied with soil type, clay loam ( $3.5 \text{ kg.cm}^{-2}$ ), sandy loam ( $1.54 \text{ kg.cm}^{-2}$ ) and sand ( $0.9 \text{ kg.cm}^{-2}$ ). The crust strength was negatively and significantly ( $P \leq 0.01$ ) correlated with seedling emergence ( $r = -0.61^{**}$ ), shoot height ( $r = -0.72^{**}$ ), and shoot dry weight ( $r = -0.61^{**}$ ) across soil types. Microscopic examinations of soil thin sections revealed that soil crusts in clay loam and sand were thicker (1 mm) than in sandy loam (0.2 mm). This investigation has shown that planting shallower (3 cm) and avoiding soil crusting especially in clay loam can lead to improved sorghum emergence and better stand in the field.

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## 1.0. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important world cereal, and in Southern Africa, it is the second most important cereal crop after maize. It is the most competitive and productive cereal crop in the rainfall zone of 600-800 mm. The bulk of the crop in the developing world is grown by resource-poor small-scale farmers mainly for subsistence (Dogget, 1988). In Zambia, sorghum is an important traditional cereal crop in dry areas (Chisi et al.1997). It covers around 4% of the area under crop production considered to be around 50,000 hectares. The area under sorghum is gradually increasing partly due to frequent droughts Zambia has been experiencing, causing the switch from maize to sorghum. Of the 50,000 hectares, 49,880 hectares are in production by small-scale farmers. Small-scale producers contribute on average 88% of the total production of the crop, whereas, the production by the medium and large-scale farmers is around 8 and 4% respectively. The national average yield is 630 kg/ha.

Zambia requires two different types of sorghum due to varying rainfall amounts. The types are tropical types, which are adapted to high rainfall areas (1000-4000 mm), and subtropical for low rainfall areas (less than 800 mm) (Chisi et al.1997). The varieties must be photoperiod insensitive with high levels of resistance to moisture stress, heat and diseases (Nath, 1995). The crop is used for both food and brewing by small-scale farmers, and there is interest to grow it for stock feed and brewing (Chisi et al.1997).

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In recent years, farmers in the Southern regions of Zambia (Region I), have reported poor sorghum seedling emergence and stand. However, the cause and the magnitude of this problem have not been investigated. According to Brar et al. (1992), surveys conducted in Australia, where quantification was done, have shown that only 55% of sorghum seed planted in the field resulted in successful plant establishment. Thirty percent of the sorghum yield potential was lost due to inadequate plant density. An important step in growing a successful sorghum crop is obtaining an optimum plant population (Brar et al. 1992). Jensen et al. (1972) state that an important phase of crop production is the successful establishment of a stand.

Region I covers the major valleys such as the Gwembe, Lunsemfwa and the Luangwa all of which lie between 300 and 900 meters above sea level. It also includes the southern parts of Western and Southern provinces at elevations between 900 and 1200 m. The mean annual rainfall in this region is low and does not exceed 800 mm. It is generally well distributed and the length of the growing season, at 70% probability varies from 80 to 120 days. Such a growing season may have as many as five 10-day dry periods of less than 30-mm rainfall. The region is the driest and most prone to drought, and is characterised by relatively high temperature during October and November just before planting. During the growing season, (November-April) the mean daily temperature may vary from 20<sup>0</sup>C to 25<sup>0</sup>C. During the cold season, mild to severe frost may be expected in the southern parts of the Western and Southern Provinces (Bunyolo et al. 1995).

According to Cardwell (1984) factors influencing seedling establishment under field conditions include the physical, chemical, and biotic properties of the soil. They also include method, date, depth and rate of seeding; and seed treatments. In addition, each of these factors interacts with the environmental factors of water, temperature, air, and light, which regulate the rate of emergence.

Lusitu is a drought-prone area, consequently, it is likely to have below optimum soil water during planting and growth of crops. The high temperatures following rainfall result in high moisture evaporation from the soil surface leading to crust formation. Optimum planting depth is seldom achieved under small-scale farmer conditions using simple tools. Seed may be dribbled into a plough furrow and covered, or into a hole dug with a hoe. The poor emergence and seedling establishment of sorghum in Lusitu could therefore be attributed to soil moisture stress, soil crusting, and non uniform planting depth. The effects of these factors on seedling emergence have not been quantitatively evaluated. The main objective of this study was to evaluate the effects of soil moisture stress, planting depth and soil crusting due to rainfall impact on sorghum emergence under controlled glass house conditions in order to explain the poor seedling emergence.

The specific objectives were:

- i) To investigate the effect of watering intervals on the emergence percentage of sorghum.
- ii) To evaluate the effects of planting depth on sorghum emergence and seedling establishment.
- iii) To establish whether soil crusts adversely affect sorghum seedling emergence.

## **2.0. LITERATURE REVIEW**

### **2.1. Seedling Emergence**

In the production of sorghum, the farmer is often faced with problems such as high soil temperature, soil crusting and low soil moisture levels, all of which adversely influence germination, emergence and stand establishment. Emergence of seedlings from the soil must precede any form of plant growth and development. In crop production, high germination percentage followed by poor emergence is of no significant value. Heatherly and Russel (1979) emphasise that only by emerging through the soil surface can a plant interact with the surrounding environment to produce the intended product.

According to Dogget (1988), the ability of a crop to establish well is very important to the small-scale farmer, because a good stand ensures high sorghum yield. The farmers may broadcast the seed before the rains, or various planting depths may be done with a hoe as early showers permit. Where ox-drawn ploughs are used, the land is rough-ploughed once showers of rain have softened it sufficiently and seed is planted. Low sorghum yields obtained in drought prone areas, even for drought tolerant crops, are attributed to poor stand establishment (Fawusi, and Agboola, 1980). This is because rainfall in semi-arid regions is often inadequate and highly erratic in distribution both within seasons and from location to location.

Rapid and uniform emergence of seedlings from the soil is an important factor in crop production (Heatherly and Russel, 1979). According to Rowland and Whiteman (1993), rapid seedling emergence reduces the period over which seedlings are susceptible to stresses, and the quicker the roots develop, the more likely the young crop is able to withstand drought. Schneider and Gupta (1985) stated that time to emergence was influenced by independent variables in the following increasing order of importance: soil temperature, water potential and soil aggregate distribution. Abrecht and Bristow (1990) found that high soil surface temperatures exceeding 50°C resulted in poor seedling emergence. Benjamin (1990) states that the point in time when the growing point of a shoot emerges from the soil into the aerial environment is one of the most easily observed events in crop development.

An important phase of crop production is the successful establishment of a plant stand with desired uniform plant density, which is directly dependent on seedling emergence (Sivaprasad and Sundra Sarma, 1987). The emergence of the coleoptile above ground brings the plant under the influence of light, suppressing mesocotyl, hypocotyl or epicotyl growth and stimulating the formation of chlorophyll (Milthorpe and Moorby, 1974). According to Vanderlip and Reeves, (1972), seedling emergence in sorghum is called stage O. This is when the coleoptile is visible at the soil surface. It occurs generally between 3 and 10 days after planting depending on environmental conditions. According to Shertz (1979), the sorghum seed germinates in three to seven days under favourable conditions. Cool temperature or dry soil can delay germination.

Stoskopf (1985), reports that studies conducted in Missouri (USA), have established the interaction of soil temperature and planting depth on the emergence of sorghum. The study involving six planting depths showed that emergence was as low as 36.9% at a 27<sup>o</sup> and 17<sup>o</sup> C day and night temperature regime and at 7.6 cm depth. Data from several studies have indicated that with a 3.8 cm planting depth, 4 days were required from planting to emergence at 30<sup>o</sup>C and 9 days at 15<sup>o</sup>C. Other work has shown that emergence ranged from five days to more than 10 days when temperature varied from 15.5 to 32.2<sup>o</sup>C and moisture conditions from permanent wilting point to field capacity.

On germination, a primary seminal root is produced. Root development of the young seedling is usually very slow. The early development of the aboveground portion of the plant is relatively slow. The mesocotyl elongates, the coleoptile pushes through the soil surface and the leaves emerge. Young sorghum seedlings with limited root systems and area grow rather slowly. At this stage, relatively minor environmental stresses such as inadequate moisture can cause considerable damage to the seedlings. Sorghum seedlings are relatively slow -growing, but after a few weeks, development is rapid and sturdy culms and many leaves are produced. Seedlings are dependent on supplies of nitrogen, phosphorus, zinc and other nutrient elements from the soil during emergence in order to achieve maximum rates of growth. The seedling establishes independence from the supplies of minerals from the endosperm some time before photosynthesis is operational (Milthorpe and Moorby, 1974).

## **2.2. Seedling emergence strength**

Seedling emergence strength is the amount of pressure the seedling should exert in order to emerge through a given soil type. Seedling emergence strength varies from as low as 0.15 Newtons for alfalfa to as high as 2.9 Newtons for maize (Cardwell, 1984). Multiple seedlings in a group are able to rupture higher-strength soil crusts. It is reported by Cardwell (1984) that studies on cotton show that the maximum thrust of one, two and three seedlings is 3.8, 5.8, and 8.5 Newtons, respectively. Large seeds exhibit greater emergence thrusts, but they also encounter more soil resistance due to the greater surface area of their emerging seedling structures. Emergence data for various plant species and cultivars are generally better for the large-seeded types when all other factors are equal.

## **2.3. Soil Physical Properties**

Soil provides plants with nutrient elements, water and physical support. In order to improve the productivity of soils, it is imperative to address those factors that adversely affect the soil's ability to hold and supply nutrient elements and water to the plants. Soil physical properties are important to the farmer because they are usually more difficult to change. For instance, if the soil is sandy, little can be done to change it into a loam or clay, but to grow crops and use techniques suitable for sand soil (Brammer 1973). Soil physical properties have been related to crop seedling emergence, because the soil physical environment can greatly modify the pattern of plant growth. The soil aggregate size has been found to influence emergence, early shoot growth, and root growth of maize (Alexander and Miller, 1991).

Other reports have shown decreasing shoot growth with increasing soil aggregate size that could be explained by neither water relations nor soil nutrient status. Alteration of soil aggregate size was observed to affect pore size and distribution, soil water characteristics, soil aeration, as well as physical impedance to roots (Alexander and Miller, 1991).

### **2.3.1. Soil structure**

The grouping of soil particles into stable collections or aggregates is referred to as soil structure (Donahue et al. 1983). Brady (1990) defines soil structure as the grouping or arrangement of soil particles; overall, combination or arrangement of the primary soil separates into secondary groupings called aggregates or ped. It can also be said to be the shape, size and degree of separation of fragments into which the soil breaks naturally when dry or disturbed (Brammer, 1973). In tropical semi-arid soils with low organic matter, soil structure is transient, being rapidly broken down by the action of rain (Rowland and Whiteman, 1993). According to Brady (1990), soil conditions and characteristics such as water movement, heat transfer, aeration, and porosity are much influenced by soil structure. The poor soil structure affects the transport of water, solutes and nutrients (Nadler and Steinberger, 1993).

According to Brady (1990), the single most important ion that causes a rapid deterioration of soil structure is sodium. Sodium does not effectively neutralise the surface negative charge on soil particles, and this results in repulsion of adjacent soil particles because of similar charges. The dispersed clays and small organic colloids move with water, lodging in the soil pores and sealing the soil.

Soil with too much sodium becomes almost impermeable to water, and it dries to hard crusts. According to Tisdale et al. (1990), sodium constitutes an appreciable fraction of the earth's crust (2.8%), and the average concentration in soils is estimated to be 0.63%. Sodium is normally found in very small amounts in soils of humid regions, but it can be a major component of soils in arid and semiarid regions.

The amounts of soluble and exchangeable sodium vary greatly according to soil type. In arid regions, sodium salts accumulating in poorly drained soils contribute to soil salinity. In fine-textured soils containing a large proportion of swelling clays only 10% exchangeable sodium can be tolerated by plants, whereas in sandy soils, the upper limit is 30%.

In one study, Fapohunda, (1986) found that seedling emergence counts were found to be higher on the well structured soil. For maize it was 81%, and it was 71% for cowpea. On the other hand, weakly structured soil, it was 73% for maize and 28% for cowpea. The breakdown of soil aggregates into a dense structureless mass during wetting resulted in hard crusts as drying occurred. It was observed that the type of crop and its mode of emergence are important factors for consideration in assessing seedling emergence. Fapohunda (1986), concluded that seedling emergence of dicotyledonous crops like cowpea, can be impeded on weakly structured soils. However, monocotyledonous crops, such as maize do better on this kind of soil.

### 2.3.2. Soil Texture

Soil texture refers to proportion of clay, silt, and sand in topsoil and subsoil down to the depth normally reached by the roots. Texture affects the amounts of nutrients and moisture which the soil can hold and the rate at which they can be lost (Brammer, 1973). According to Williams et al. (1983), particle size composition and field texture were confirmed to be the soil properties with consistent association with nature of the moisture characteristic. Soil texture is important in that it determines water intake rates, water storage in the soil, the ease of tilling the soil, the amount of aeration (vital to root growth), and it also influences soil fertility. Coarse textured soils easily lose nutrient elements, which can be leached away rapidly in drainage water, resulting in lower in nutrient content than clay soils. A coarse sandy soil is easy to till, adequately aerated for good root growth, easily wetted, and dries up quickly.

High clay content soils (over 30% clay) have very small particles that fit together, leaving little open pore space, meaning little room for water to flow into the soil (Donhue et al. 1983). The size of particles in mineral soils is not readily subject to change (Brady 1990). Thus, a sandy soil remains sandy. Heil et al. (1997) observed that in coarse-textured soils, surface seals occurred in soils with clay contents greater than 5%. Surface seals form quickly during rainfall and these reduce water infiltration. Clay content was found to have the main influence on surface sealing. Silt plus clay contents of soils are considered a better indicators of soil sealing than the silt content alone because silt sized clay aggregates can behave as silt particles in the process of clogging pores. Iron and Aluminium oxides were found in higher amounts at sealed soil sites, but they did not play a major role in soil sealing.

The soil with a combined silt and clay content of more than 15% formed a two layer structural seal, whereas coarse textured soils developed 4-layer structural seals (Heil et al. 1997). Nuttall (1982) found that silt percentage was positively correlated to crust strength.

### **2.3.3 Porosity**

Porosity refers to the number and sizes of pores in the soil, through which water and air pass and enter. That is, the portion of the soil volume occupied by air and water and is determined largely by the arrangement of the solid particles resulting in pores of various sizes (Brady, 1990). Thus if particles are packed close together as in sands, or compacted as in some subsoils, the total porosity is low. If, however, they are arranged in porous aggregates, as is often the case in medium textured soils high in organic matter, the total porosity will be high (more than 50%).

Donahue et al. (1983) points out that pore spaces consist of that portion of the soil volume not occupied by solids, either mineral or organic components and that under field conditions pore spaces are occupied at all times by air. Sands have large and continuous pores; medium sands have pore size diameters of greater than 0.2 mm (200 microns). Although clays contain high total pore space because of the minute size of individual clay particles, they have very small pores (<0.002mm) that transmit water slowly. The most rapid water and air movement is in sands and strongly aggregated soils, whose aggregates act like sand grains and pack to form many large pores.

Reduced air filled porosity can result in reduction in the root penetration (Asady et al. 1985), and according to Cardwell (1984), this is a problem in stand establishment on fine textured soil with poor soil aggregation and low organic matter.

#### **2.3.4. Bulk density**

Mali et al. (1977) and Fapohunda (1986) reported reduced seedling emergence with increasing bulk density, soil strength and decreasing oxygen diffusion rates, and that the increase in bulk density up to  $1.2\text{g/cm}^3$ , decreased emergence of some sorghum varieties. However, Brady (1990) reports that the effect of bulk density on crop performance can be noticed at bulk density of  $1.6\text{ g.cm}^{-3}$  or above. Fine textured soils have low bulk densities when not compacted, but very high densities when compacted, and sandy soils are less variable in their degree of compactness than fine textured soils.

Higher soil bulk densities have been found to create oxygen-stressed environments for the roots and to reduce the mean diameter of air filled pores. This may lead to a very poor seedling establishment. The system of crop and soil management employed on a given soil influences its bulk density. Continuous cropping increases bulk density and decrease pore space (Asady et al. 1985). Heavy rainfall after planting can increase the bulk density of the soil in the seedbed to values that inhibit emergence (Rowland and Whiteman, 1993).

### 2.3.5. Drainage

Drainage is evaluated through the effect of texture and porosity on permeability. The colour of the soil is often related to drainage. For instance, red soils indicate a well-drained soil. Grey and black colours often indicate poor drainage. Some sands, which have good or excessive drainage, are black, brown, yellow or almost white. Topsoils of well-drained red soils may be grey or black owing to humus staining (Brammer, 1973). A poorly drained soil may lead to poor seedling emergence or no emergence at all, due to lack of oxygen because of poor diffusion rates. Seedling establishment can also be affected because there is loss of nutrients under excessive conditions of moisture, because nitrogen for example is lost through microbial denitrification. Fine textured soils are prone to this situation.

### 2.3.6. Soil water

Soil water makes up the soil solution which is the critical medium for supplying nutrients to growing plants (Brady, 1990). Soil water contains soluble constituents, including nutrient elements (e.g. Calcium, Potassium, Nitrogen and Phosphorus). According to Aina and Periaswamy (1985), water retention characteristics show large differences between soils and within soils. Water in the soil pores is held with varying degrees of tenacity depending on the amount of water present and the size of the pores. The sorghum stand establishment has been reported to be adversely affected by soil water stress and unfavourable soil physical and chemical properties (Brar et al. 1992). Nelson and Larson (1984) report that plant available soil water is the likely major factor influencing seedling emergence and survival.

Seedlings emergence fails due to lack of adequate water long enough for the seedlings to become established. Soil water at seeding may be below the optimum level for growth and development. Water content in soils has an effect on soil formation, erosion, and structure stability, but the most important aspect is the availability of water for plant growth. The amount of water present in a soil at any given time has a direct influence on the concentration of the soil solution. It constitutes one of the main factors determining the ease with which the soluble nutrients can be absorbed by roots of plants (Klages, 1942). Soil moisture condition exerts a dominant influence on stand establishment because of the modifying effects of moisture on soil properties. Heavy soils may hold excessive moisture for longer periods, which can affect crop establishment adversely. On the other hand, sandy soil may lose moisture within a short time if high temperatures follow rain. Furthermore, reduction in soil hydraulic conductivity or seed-soil contact reduces rate of water uptake and delays germination.

Percent seedling emergence under field conditions varies with soil moisture content, soil type and plant species. Soil moisture tension has a direct effect on availability of water for uptake by plants. Work carried out with many crops shows that total emergence is affected only slightly by moisture tension from 0.5-3 bars. The number of emerged seedlings decreases rapidly at moisture tensions greater than 7 bars, and the time to maximum number of emerged seedlings increases as moisture stress increases (Cardwell, 1984).

Soil structure, soil water potential, and seed-soil surface contact determine the rate of moisture uptake by the seed in soil. According to Cardwell (1984), many crop seeds are able to imbibe sufficient water at moisture tensions near or slightly below the permanent wilting point (PWP) which initiates germination but fail to emerge. That is, the radicle and the hypocotyl fail to elongate. Soil moisture around permanent wilting point is not enough for seed crops to emerge. Different crops have optimum moisture regime to initiate emergence, and deviation from the optimum results in adverse effects leading to poor stand.

Studies conducted on lucerne established that emergence of the crop is strongly influenced by soil moisture tension, which affects water availability. Triplett and Tesar (1960) reported that emergence was inversely related to soil moisture tension, and that no emergence occurred at tensions greater than about 11 bars. Lyles and Fanning (1964) observed that the total emergence of grain sorghum decreased from about 96 to 86% as soil water tension increased from 0.3 bars to approximately 8 bars. Thereafter, total emergence decreased very rapidly. According to Heatherly and Russel (1979) other work has shown little or no change in emergence rates of sorghum when soil moisture tension was 4 bars or less.

Nuttall (1982) observed that emergence of rape seedlings on several soils was zero when moisture was below 50% of the moisture content at field capacity. Average emergence of seedlings grown on soils at field capacity was significantly greater than on soils watered to 50% field capacity.

However, Fawusi and Agboola (1980) observed increased emergence with decreasing soil moisture regime in a Sandy Loamy soil. Seventy-five percent to 100% soil moisture regime gave 10-25% sorghum and millet emergence compared to 75 –86% emergence with 25 –50% soil moisture regime. An interaction between the soil type and the soil moisture regime was also observed, indicating that the effect of soil moisture on seedling emergence was not of the same magnitude among different soil types. Soils with low content of silt gave the highest emergence even at low moisture regime.

Heatherly and Russel (1979) reported that soybean plants emerged from clay at a faster rate and over a wider range of soil water potential than from the silt loam soil. Total emergence from clay soil after 14 days exceeded 81% and the range of emergence from silt loam was 31.7 to 90 %. The range of the soil water potential for optimum emergence for the silt loam soil was much smaller than that for the clay soil. It was further observed that optimum soil water potential of a medium textured soil (silt loam soil) is critical for both seedling emergence and subsequent seedling vigour and survival. Soil moisture is usually managed by firming the soil around the seed to increase soil-seed contact, which causes a capillary flow of water that carries the soluble ions toward the seed as it imbibes water. Thus, pressing the soil around the seed to obtain better contact between soil and seedling improves emergence (Nelson and Larson, 1984).

### 2.3.7. Soil Crusting

Soil crusting is the formation of dense surface layer of soil characterised by increase in soil strength due to soil compaction and loss of soil structure. Crusting increases the resistance to shoot penetration, and this is frequently the problem in poor stand establishment on fine-textured soils with poor soil aggregation and low organic matter (Cardwell, 1984). According to Heydecker (1956), seedling emergence is influenced by events causing changes in soil structure such as formation of soil crusts. Sorghum seeds are small and are unable to emerge if the soil surface is hard or crusted (Stoskopf, 1985). According to Holder and Brown (1974), extensive areas of cultivated soil throughout the world develop crusts that impede seedling emergence, and soil crusts adversely affect both the profile water regime and the fate of crop seedlings (Helalia and Letey, 1989). Rainfall impact on the soil surface is one of the several factors that cause compacted surfaces. The response of crop plants to surface crust varies with the nature of their emergence (Sivaprasad and Sundara Sarma, 1987).

The degree of surface crusting depends on the intensity of slaking forces and on the structural attributes of the surface soil in relation to its reaction to these forces. If the soil is well drained and does not have compacted layers the degree of crusting is lessened. The soil that allows the infiltration and percolation of water even when rainfall is intense experiences minimal crusting. The thickness of the crust and its strength varies with the nature of soil, slaking forces and the condition of drying. Soils that are low in organic matter such as sandy soils have unstable structures and are likely to have thicker crusts.

Saline soils also have structural instability resulting from the deflocculation of soil clay particles caused by the high proportion of sodium among the exchangeable cations. High exchangeable sodium (ES) and low organic matter in sodic soil render soils extensively prone to crusting. The formation and permeability of a soil crust depends on the exchangeable sodium percentage (ESP) of the soil and on the electrolyte concentration of the percolating solutions. It tends to decrease with increasing ESP and decreasing electrolyte concentration (Painuli and Abrol, 1986).

Soils having higher drying rates such as sandy soils and cracking clays are also prone to crusting. Soil surface seals may consist of dense surface skin seal and/or a washed-in layer of dispersed clay just below the surface. The surface soil aggregates are most vulnerable to destruction, especially by heavy rains. The dispersed surface tends to seal over and prevent water infiltration. When the soil dries, a hard crust is formed and this impedes the emergence of seedlings. The seedlings are only able to emerge through cracks in the crust. Brady (1990) reports that such crusts often spell disaster to an emerging crop. A gradual deterioration of soil structure and the consequent partial sealing of the profile by the formation of a surface crust may occur in some soils under certain conditions such as increase in salinity. Morin et al. (1989) and Agassi et al. (1985) report that crust formation is due to combined effects of energy due to the impact of raindrops and the dispersion of clay particles at the soil surface.

In Georgia, USA, soils of the Piedmont region with clay contents above 10% can form low-permeable seals (Rediclyffe et al. 1991). Surface seals can form when raindrops strike the soil surface and create a thin layer of low hydraulic conductivity. Soils that are prone to sealing and crusting were found to have pH values of 1.3 units lower than those of unsealed sites do. The organic carbon contents of sealed sites were low (1-2 g per kg) at 0-50mm depth and slightly higher at unsealed sites (Heil et al. 1997). Nuttall (1982) observed that organic carbon percentage was inversely related to crust strength.

### **2.3.7.1 Mechanisms for the formation of crusts**

According to Hillel (1980), crusts develop under the beating action of raindrops, and because of the spontaneous slaking and breakdown of soil aggregates during wetting. The action of raindrops striking at an exposed soil surface is related to its kinetic energy. Surface seals form due to soil structural breakdown under raindrop impact or rapid wetting (Chen et al. 1980). This leads to the deposition of fine particles from the resulting soil to form a suspension, dispersion, and illuviation of fine particles. Consequently, plugging of pores below the surface occurs (Gal et al. 1984).

Smith (1993) reported that soils in arid regions often have low organic matter content, high proportions of fine sand and silt, and a high percentage of calcium carbonate, all of which lead to crusting.

Gal et al. (1984) studied seal formation in clay and sandy loam soils from Israel. It was concluded that chemical dispersion and the formation of a washed-in layer was the dominant process responsible for the reduction in seal conductivity in soils with exchangeable sodium percentage of less than 15%. In a study on crust formation by simulated rainfall on fine sandy loam by Heil et al. (1997), microscopic examinations of crusts revealed that the top 1 to 3cm of soil was very dense and devoid of large air pores. The permeability of these crusts to water was greatly reduced in comparison to that of normal soil.

In silty clay loams of Colorado, crusts appeared to limit stand establishment by preventing emergence rather than prevent germination. Seeds typically sprout and large seedlings can live several days beneath crusts. Ben-Hur et al. (1985) found that soil texture affected crust conductivity in Israel soils with the impermeable crusts occurring at clay contents of approximately 20%. This behaviour was attributed to the formation of unstable aggregates at clay contents substantially above 20% and to the clogging of pores. Most seedlings emerge as soon as crusts are broken by tillage or softened by water. Mah et al. (1992) found that determination of the hydraulic conductivity (K) provides some evidence of some surface sealing with rainfall.

The data obtained by Glanville and Smith (1988) indicate that some surface sealing may occur due to rainfall impact on the soil if 37% of soil particles are less than 0.002-mm diameter (clay).

Detachment of some of these particles and aggregates of small size would presumably lead to the formation of some degree of surface sealing. The occurrence of high strength at or near the soil surface associated with crusting and hard setting has been observed in semi-arid environments (Mullins et al. 1987). According to Karl et al. (1992) high soil drying rates can result in the early onset of high soil strength, which adversely affects to seedling emergence. Climatic conditions that are typified by high solar radiation, high temperature, and low relative humidities, often cause rapid drying of the soil surface. This leads to high soil strength and high soil temperature, both of which are detrimental to seedling emergence and plant growth and seedling emergence.

According to Mullins et al. (1987) high soil strengths have been observed to be due to high soil temperature under conventional tillage systems, leading to the rapid oxidation of soil organic matter which results in poor aggregate stability. Al-Durrie and Bradford (1982) report that high soil strength is due to high rainfall intensity providing kinetic energy for aggregate destruction that leads to crusting. High soil drying rates lead to early onset of high soil strength. Soil strength is influenced primarily by bulk density (texture and soil particle aggregation) and moisture content, with some modification by organic matter and base saturation. As soils dry, soil strength restricts emergence before soil moisture limits cell division and elongation.

Seedling emergence through the crust is controlled by the size, their number and spacing of the seedlings, cracking pattern of the soil; and the strength of crust around the emerging seedling (Cardwell, 1984).

According to Karl et al. (1992) soil strength can influence emergence. The rapidity with which soil strength develops is the crucial factor influencing the success of emergence. The study conducted by Karl et al. (1992) revealed that soil strength began to impede shoot growth at a cone index of 11 bars, and by 20 bars all growth and hence emergence ceased.

Osman et al. (1985), report that sorghum has poor emergence when soil is crusted because of the small seed size and the consequent low penetration strength or poor lifting capacity of the emerging seedlings. However, they found genetic variability among sorghum genotypes for emergence through crusted soil. Wheat emergence was found to be affected by crusting in that coleoptile growth and root elongation were markedly reduced in the range 0-0.022 bars such that total emergence was reduced to 7% at 0.003 bars in a fine sand. It was found that coleoptile elongation was more affected than root elongation by the same mechanical stress. Roots were thicker and the coleoptiles thinner under increasing soil shear strength conditions, and their elongation was considerably reduced by a shear strength as low as 0.022 bars. The reduction in coleoptile length resulted in reduced emergence (Collis-George and Yoganathan, 1985).

In one study, Sivaprasad and Sundra Sarma (1987) found that the mean time of emergence increased with increase in rain drop size and depth of planting. It was observed that crops differ in their emergence capacity (ability to push through the crusts) under adverse soil conditions, such as thick crusts.

The impact of larger raindrops enhanced soil compaction at the soil surface because of greater soil structural breakdown. Chickpea delayed to emerge and Pigeonpea failed completely to emerge under this condition. Pearl millet was found not to be adversely affected by drop size but by planting depth, meaning shallower planting is better for pearl millet. Varietal differences were also noted in response to rain drop size. Nuttall (1982) observed that crust strength was related to emergence of the rape seedling under a wide range of soil conditions. The conclusion from this study was that crust strength measurements might be used as general index of how the soil physical condition may affect rape seedling emergence.

## **2.4. Soil chemical properties**

### **2.4.1. Salinity**

Benjamin (1990) reported that increasing salinity of soil water causes a reduction in the magnitude of the emergence force exerted by seedlings. Salts that increase the salinity of the soil water can have the opposite effect of stimulating seedling growth by supplying essential mineral nutrients such as phosphorus (Costigan, 1984). Other research work has shown that adding nitrogen fertilisers to soils before planting has reduced the percentage emergence, presumably because of osmotic effects. Addition of 75 or 150 kg of nitrogen per hectare prior to sowing onions increased the standard deviation of emergence time by about half a day meaning delayed emergence due to increase in nitrogen (Benjamin, 1990). According to Cardwell (1984), emergence is related to the combined stresses of moisture and osmotic potential. Emergence declines rapidly when the combined forces exceed 8 bars.

Soil salinity has been found to adversely affect emergence of seedlings (Benjamin, 1990). Emergence gets affected at moisture suctions of approximately 4 bars and  $1.4 \text{ dSm}^{-1}$  of electrical conductivity or at 0.5 bars of moisture suction and  $6 \text{ dSm}^{-1}$  of electrical conductivity (Cardwell, 1984). Bauder et al. (1992) established that alfalfa seedling emergence and rate of seedling mortality can be significantly affected by soil salinity at the time of seeding. Alfalfa seedling emergence was reduced by as much as 50% and seedling mortality was increased from 20 to 60% by irrigation water having high salinity (SAR of 5.1 to 9.6). According to Cardwell (1984), crops exhibit a wide a wide range of salt tolerance both between and within species. Saline soils containing more than 0.2% soluble salts and EC greater than  $4 \text{ dSm}^{-1}$  give reduced emergence and final emergence percentage of sorghum. Salt concentration in a saline soil increases as moisture content decreases. Climatic conditions generally influence the sensitivity of most crops to salinity, that is, salinity generally increases during dry hot weather.

## **2.5. Planting Depth**

Depth of planting influences the length of time from planting to seedling emergence. Planting deeper than the recommended depth for a region may delay seedling emergence. Unless local conditions dictate deeper planting, seeds of most cereals should be placed 2-4 cm in the soil in order to ensure rapid emergence (Stoskopf, 1985). According to Nelson and Larson (1984), a rule of thumb for planting depth of many crops is 4 to 5 times the average seed diameter.

Other factors influencing planting depth include type of emergence ( hypogeal or epigeal ), soil texture, date of planting, and available moisture supply. Rate of emergence is affected by soil temperature and moisture conditions while percent final emergence is associated with depth. Nelson and Larson (1984) report that maize emergence is delayed 1-2 days with each 2 to 3 cm increase in depth, particularly with early season planting. Shallow plantings fail due to rapid soil drying near the surface, and the rate of soil drying varies with soil depth. Therefore, slight increases in planting depth may make large differences in amount of moisture available to the seed. A seed planted 2 cm deep may require 10 days to emerge and could dry out before emerging, whereas planting 4 cm deep could avoid the problem.

Cardwell (1984) reported that greater planting depths are recommended for sandy soil than clay soil due to lower holding capacity and faster drying rate at a given depth of sandy soils. It is reported that in regions where planting occurs during periods of low rainfall and low soil moisture availability, planting depth may be double or more the depth commonly used in more moist regions. Stuck (1976) reported that since soil moisture generally increases with depth, deeper planting might be advantageous to help ensure an optimum seedling emergence.

Increased soil compaction is also reported to be an advantage in dry areas because it increases seedling emergence. Soil compaction can improve emergence from shallow planting depth because rapid drying of the surface is avoided due to better capillary water movement.

During dry years, placing maize up to 12.7 cm deep produces better stands than shallower placement while no difference in final emergence is noted for planting at 2.5 –7.5 cm in most years (Cardwell, 1984). Seedling emergence of various crops has been found to vary with both soil type and planting depth. Banting (1979) observed high emergence of barley on all soil types for seeds planted at 2.5 cm. Good emergence was observed in heavy soils, less in loam and fine sandy loam. There was poor emergence in any of the soils where seeds were placed at a depth of 7.5cm to 12.5cm. In rape, Nuttall (1982), found that emergence was greater at shallower planting depth for all soil types. Because of the greater crust strengths of some soils, seedling emergence percentage was low at both planting depths (shallow and deep) resulting in significant soil type by planting depth interaction.

Stoskopf (1985) reported that sorghum seeds are best-planted about 2.5 cm deep, and at 5 cm deep in dry warm soil. It is suggested that if the seed is planted deeper than this, the plumule will emerge from the coleoptile, but it may not be able to penetrate to the soil surface. According to Stuck (1976), when seeds are planted too deep they may fail to emerge due to failure of of hypocotyl extension during emergence and increased soil resistance. This may delay or prevent emergence. However, Cardwell (1984) reported that the maximum depth from which sorghum can emerge is 7.5 to 12.5 cm. Rowland and Whiteman (1993), state that there is no advantage in deep planting in semi-arid areas. The seedlings take longer to emerge and so they become susceptible to insect or disease attack or desiccation.

### 3.0. MATERIALS AND METHODS

The study was conducted in the glasshouse at the School of Agricultural Sciences, University of Zambia, Lusaka. The experiments were conducted to determine a). Effects of watering interval on sorghum emergence and seedling establishment, b). Effects of planting depth on sorghum emergence and seedling establishment, and c). Effects of raindrop impact and soil crusting strength on sorghum emergence and seedling establishment. Three soil types were used in the study namely, a sand soil, a sandy loam and a clay loam. The sand and clay loam soils were collected from Lusitu in Siavonga District in the Southern Province where poor sorghum emergence and seedling establishment has been observed. Lusitu is located between latitudes  $15^{\circ} 18' S$  and  $17^{\circ} 28' S$  and longitudes  $28^{\circ} 36' E$  and  $28^{\circ} 42' E$ . The sandy loam soil, which was used as a check, was collected from the Field Station at the School of Agricultural Sciences, located at 1140 m above sea level, latitude  $15^{\circ} 22' S$  and longitude  $28^{\circ} 20' E$ . Each of the soils was air dried and ground to pass through a 4.75mm sieve before use. Some selected properties of the soils used in the experiments are presented in Table 1. A certified sorghum seed of variety Kuyuma, was used as a test crop in all three experiments. The germination percentage of the seed was assessed at 96%.

Three independent experiments were conducted, and each was analysed separately. Therefore, there are no direct comparisons between the experiments.

**Table 1. Some selected properties of the soils used in the study.**

Chemical properties														
Soil type	pH in CaCl <sub>2</sub>	EC mS cm <sup>-1</sup>	Organic Matter (%)	Total N (%)	Avail-able P	Na	K	Ca	Mg	Zn (mg/kg)	ESP%	FC		
												Index (mm)	Saturated Hydraulic Conductivity (K) cm/hr	% Moisture content (cm <sup>3</sup> /cm <sup>3</sup> )
Sand	5.41	0.46	0.96	0.04	27.65	0.33	1.23	2.73	1.27	0.56	5.94	15.42	10.01	5.41
Sandy loam	6.18	0.90	2.32	0.06	9.45	0.77	0.74	7.29	2.50	2.44	6.81	18.07	12.55	5.53
Clay loam	5.48	1.33	6.52	0.14	41.30	1.12	2.77	10.35	10.34	2.10	4.56	30.01	16.52	14.21
<b>Physical Properties</b>														
Soil type	Bulk Density g.cm <sup>-3</sup>	Total Porosity (%)	Aggregate instability Index (mm)	Saturated Hydraulic Conductivity (K) cm/hr	FC									
					% Moisture content (cm <sup>3</sup> /cm <sup>3</sup> )	PWP	PAW							
Sand	1.55	41.50	0.15	14.21	15.42	10.01	5.41							
Sandy loam	1.30	50.94	0.83	4.00	18.07	12.55	5.53							
Clay loam	1.38	47.92	1.53	1.11	30.01	16.52	14.21							

FC = Field Capacity

PWP = Permanent Wilting Point

PAW = Plant Available Water

## Experiment 1

The first experiment was conducted to determine the effect of soil type and watering interval on sorghum seedling emergence and establishment. The soil type had three sub-variables and the watering interval had four levels. The three soil types were, sandy loam, sand and clay loam, and the watering intervals were 2, 4, 6, and 8 days. The experimental design consisted of twelve treatment combinations of three soil types and watering interval replicated four times and arranged in a randomised strip plot design.

The moisture content of the soils at field capacity (0.33 bars) and at permanent wilting point (15 bars) was determined gravimetrically. Four samples, of each soil type in small rubber rings (5-cm diameter) placed on pressure plate apparatus were saturated for 24 hours. The samples were then subjected to pressures of 0.1, 0.33 and 15 bars, for another 24 hours. After this time in the apparatus, the samples were removed, weighed and further dried for 24 hours at 105<sup>0</sup>C in the oven. The samples were weighed again after drying to determine the amount of moisture held at field capacity and permanent wilting point respectively. The moisture contents of the soils at these two soil moisture status are given in Table 1.

For planting, 48 pots of 17-cm x 17-cm upper surface area and 17-cm height were filled with the soil to about 14-cm to the top. The soil was levelled and 16 seeds were sown and covered with 3-cm thick layer of soil. Each pot contained 5 kg of soil, and the pots were watered individually to half the moisture content of soil held at field capacity as determined in preliminary experiments.

The pots were weighed every time before watering in order to determine the amount of water to add to the soils to maintain the moisture at half field capacity (0.33 bars) of the specific soil type.

Seedling emergence counts were made every two days starting from the 4<sup>th</sup> day after planting (DAP) to ten days after planting. Thereafter, the seedlings were thinned, and four seedlings were left in each pot for the study of seedling establishment. The seedlings grew for 18 days, and data collected at the end of the experiment were shoot height and shoot dry weight. The experiment lasted for 28 days.

## **Experiment 2**

The second experiment was conducted to evaluate the effects of planting depth on sorghum emergence. The three soil types used in the first experiment were the same for the second experiment. There were three planting depths (3 cm, 6 cm, and 9 cm), chosen to simulate various planting depths to which farmers can plant their seed. The experimental set up was a 3 x 3 factorial arrangement of 9 treatment combinations of soil type and planting depth in a randomised complete block design with four replications. Thirty-six plastic pots with 15 cm internal diameter at the top and 16.5 cm height were used. The pots were filled with 3 kg soil, and twelve sorghum seeds were sown and covered with either 3 cm, 6 cm or 9 cm, thick layer of soil depending on the treatment. The moisture content of the soil was maintained at 50% of that held at field capacity for each soil type.

Seedling emergence counts were made and recorded every three days after planting (DAP) and continued up to 15 DAP, after which the seedlings were thinned leaving one seedling per pot in order to evaluate seedling growth performance. At 28 DAP, the plants were harvested, and the combined shoot height and shoot dry weight of the four replicates of each treatment were recorded.

### **Experiment 3**

In this experiment, the effect of raindrop impact and soil crusting strength on sorghum emergence was studied. Three soil types were subjected to simulated rainfall using three-drop sizes (3 mm, 4 mm, and 5 mm). A randomised complete block experimental design was used with three soil types, three-drop sizes and four replications.

To simulate rainfall, three plastic pots of 15 cm x 15 cm, surface area and shorter height of 17 cm were used. The pot bottoms were drilled using nails of three different to make holes of sizes of 3 mm, 4 mm and 5 mm in diameter. The amount of water applied through the holes in the pots was close to the amount received in ten days in Lusitu (30 mm). This was approximately 540 cm<sup>3</sup> per pot of 177-cm<sup>2</sup> surface area, giving an intensity of 3.1 cm<sup>3</sup> /cm<sup>2</sup>.

Thirty-six plastic pots measuring 15-cm upper surface diameter and 16.5-cm height were planted with seed. The pots were filled with 3 kg soil to a height of 12 cm from the bottom and levelled. Twelve seeds were then sown and covered with 3-cm thick layer of soil.

These pots were then individually subjected to simulated rainfall of the different water drop sizes. The water was delivered onto the planted pots from a height of 1.5 m above each pot during watering, and this was done every three days.

Seedling emergence counts were made every two days starting from 7 DAP ending 15 DAP. Crust strengths were measured using a pocket penetrometer (Eijelkamp 6987 em giesbeek) every three days before applying water.

At 15 DAP, the seedlings were thinned and one seedling was left per pot for evaluating seedling growth performance. Shoot height, and shoot dry weight were measured at 28 DAP, and the data from the four replicates of a treatment were combined.

### **Measurement of soil strength**

In addition, the modulus of rupture of the soil samples was determined. The modulus of rupture is a physical soil property that can be measured on soil peds, soil clods and aggregates. The parameter has been found to be related to seedling emergence. It indicates the amount of pressure the seedling should exert in order to emerge through a given soil type. To measure the modulus of rupture, soil clods, or undisturbed soil cores are used. The undisturbed core sample is placed on its side on a horizontal plate, and the crushing force is applied through another horizontal plate above the core. As the force is increased, the sample ruptures along a vertical plane passing through the axis of the core. The value of the applied force at which the soil core ruptures is recorded.

To prepare the samples, soil passed through 4.75 mm sieve was used. Small cylindrical bottles measuring 7 cm in height and 5 cm diameter were filled with the soil. The soils were then watered to saturation before being left to dry. The modulus of rupture of the prepared clods was measured on a Russian compression machine, TVIN NCY-50-N2050.

### **Preparation of soil thin sections for microscopic studies**

Soil passed through a 4.75 mm sieve was used. The three soil types were placed in plastic pots measuring 15 cm upper surface diameter and 16.5-cm height, and each soil type was replicated three times. Each pot was filled with 3 kg of soil to 15 cm from the bottom and levelled. One Kubiena box measuring 3 cm x 5-cm x 3 cm was then inserted into each pot. The soils were then individually subjected to simulated rainfall of the 5 mm water drop size. The watering was done every three days for 12 days. The amount of water added per pot and the procedure for watering were similar to that of the sown pots in the experiment. After 15 days the soil samples collected in the Kubiena boxes were taken to the laboratory for the preparation of soil thin sections.

### **Preparation of the soil samples**

The soils were first dried by replacing the water within the samples with acetone. The samples were placed in a dessicator above a beaker filled with acetone. Air was removed from the dessicator using a vacuum pump until the environment was saturated with acetone vapour. This procedure was repeated daily for one week.

The soil samples were then impregnated using a mixture of 750 ml of polystyrene resin, 500 ml of acetone, 2 ml of the catalyst cyclohexano peroxide, and 1-ml of the accelerator cobalt octoate. The samples were impregnated under vacuum in a dessicator to obtain good penetration by the resin. The resin was delivered through a polyvinyl-tube regulated by a tap . The samples were kept for 10-15 minutes under vacuum before the tap of the polyvinyl tube was opened slightly and the resin was introduced through a separation funnel mounted above the desiccator to slowly fill the containers holding the samples. Following the delivery of the resin, the vacuum was maintained for 10 minutes. Thereafter, the vacuum was released and the impregnated samples were removed from the dessicator and stored five weeks to harden. After this time, the samples were removed from the Kubiena boxes and plastic containers.

### **Cutting, Grinding and Polishing**

Small slices from the soil samples were then cut off with a German-made cutting machine. The machine consisted of a cutting disk with diamond plated edges and was cooled by a jet of oil during cutting. The slices obtained after cutting were then polished on one side by hand grinding with different grades of Carborundum (Silicone carbide) on flat glass plates in order to prepare sections for mounting onto glass. The grades of Carborundum used were 150, 400, 600, and 800, the coarsest grain being 150 and the finest 800. The samples were first ground with the coarsest grain, and the polishing was continued with finer grade of 800. Oil was used as a lubricating agent instead of water to avoid water reacting with readily soluble compounds within the samples.

### **Mounting soil thin sections**

After cleaning, the polished sections were mounted on the object glasses. To increase the adhesion of the sections on the glass, one side of the glasses was ground slightly with the finest abrasive powder. The samples were mounted onto the glass using Epoxy resin, taking extra care to avoid trapping air bubbles between the slide and the sample. The mounted samples were then turned upside down on the table with the object glass on top of the sample. The samples were then left for 24 hours to let the resin harden. After mounting, the thickness of each sample on the side that was not mounted was reduced by sawing off a large part of it using the same cutting machine employed earlier on. When cutting off the excess sample, the mounted sample was held by a suction device.

The thickness of the remaining part of the sample was further reduced by hand grinding on a glass plate using Carborundum 150 followed by Carborandum 800. The thickness of the thin section was frequently monitored with the aid of a microscope. In order to remove the Carborundum particles from the sample surface, the sample was rubbed on the glass plates using oil. When the thin sections had reached a thickness of about 40 to 50 microns, they were covered with a cover-glass. The cover glass was mounted using Epoxy resin.

### **Microscopic observation**

The mounted samples were studied using Austrian made Reichert Neoval-Pol polarizing microscope at the magnification of 32x to examine features of crusts and the layers of mineral particles within the samples.

The features that were observed were size of aggregates, arrangement of the soil particles, thickness of the crust, colour of the crust, and frequency and size of the pores.

### **Statistical analysis**

Before the percent seedling emergence data were analysed statistically, the arcsine transformation was performed. According to Fapohunda (1986), data expressed as percentages or proportions of the total sample generally have binomial rather than normal distribution, and this transformation changes the data to those having normal distribution. An arcsine or angular transformation is appropriate for data on proportions, data obtained from a count and data expressed as decimal fractions or percentages (Gomez and Gomez, 1984). Data on shoot height and shoot dry weight were not transformed. One plant left per pot was left to evaluate seedling growth performance in the second and third experiments because of the small amount of soil and small pot size that were used compared to the first experiment. Therefore, in the analysis the four replications per treatment were combined, and this was adequate to produce reliable results.

In all the three experiments, an analysis of variance was conducted using the MSTATC statistical package with MGRAPH version 2.10 (Michigan State University, 1988). The analysis of variance was used to analyse all the variables. Because seedling emergence was observed at different times, the time of observation was used as an additional factor. Data from all stages of observation were combined and a single analysis of variance was obtained.

In the first experiment time of observation as a factor became a subplot and in the other two experiments it became a third factor in the analysis of measurement of time outlined by Gomez and Gomez, (1984) in discussing analysis of measurement of time. Treatment means were separated using the Least Significant Difference or Duncan Multiple Range Test. Where the data used in the analysis of variance were transformed, treatment means are presented as the original untransformed values.

## 4.0. RESULTS

### **Experiment 1. Effect of watering intervals on sorghum emergence and seedling establishment.**

Percentage emergence data at 4 days to 10 days after planting (DAP) taken at 2 day intervals are shown in Figure 1. Percent seedling emergence was calculated as the number of emerged seedlings to the number of planted seeds. Increasing watering intervals from 2 days to 8 days did not affect total seedling emergence at 10 DAP from all the soils. There were no significant differences in seedling emergence and establishment due to watering intervals and soil types (Appendix 2). Days after planting significantly ( $P \leq 0.01$ ) affected emergence of seedlings (Appendix 1).

There was significant interaction between days after planting and soil type, indicating that seedling emergence at a particular day after planting was not of the same for all soil types (Appendix 1). By the fourth day after planting, 78% emergence averaged over watering intervals was recorded from the clay loam soil, whereas for the sandy soil and the sandy loam soil, emergence levels of 53% and 68% were recorded respectively. Emergence percentage on the fourth day was significantly higher ( $P \leq 0.01$ ) in the clay loam and the sandy loam than in the sand. At 6 DAP emergence in all soils across the watering intervals was above 90% (Figure 1). Figures 2 and 3 show seedling growth characteristics at four watering intervals in three soil types. Shoot height significantly ( $P \leq 0.01$ ) varied with soil type. It was significantly higher in the clay Loam, than in the Sand and the sandy loam (Figure 2). Similarly, shoot dry weight (Figure 3) was significantly ( $P \leq 0.01$ ) higher in clay loam soil than in both sand and sandy loam soil respectively.

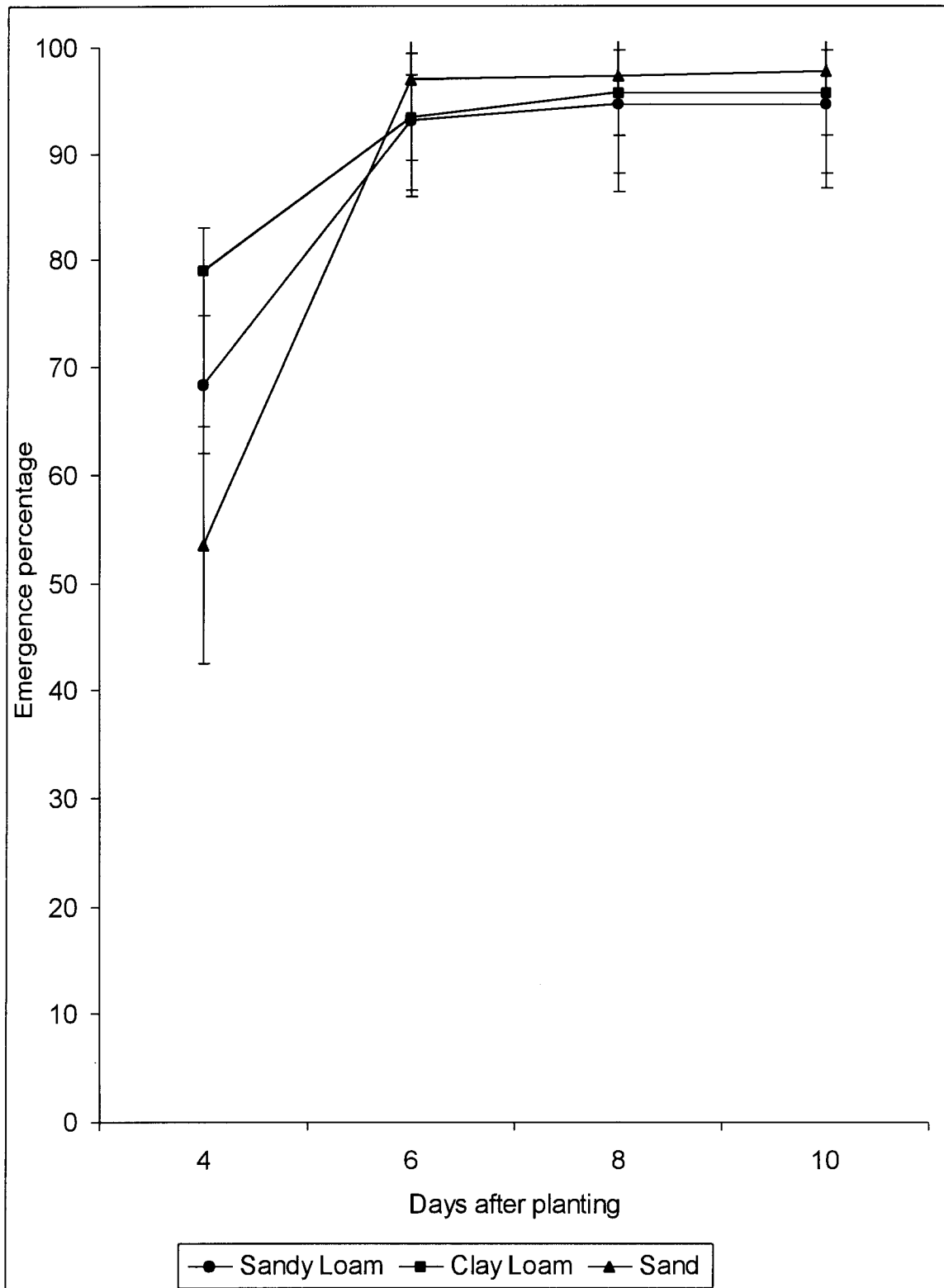


Figure 1. Influence of soil type on seedling emergence percentage with time.

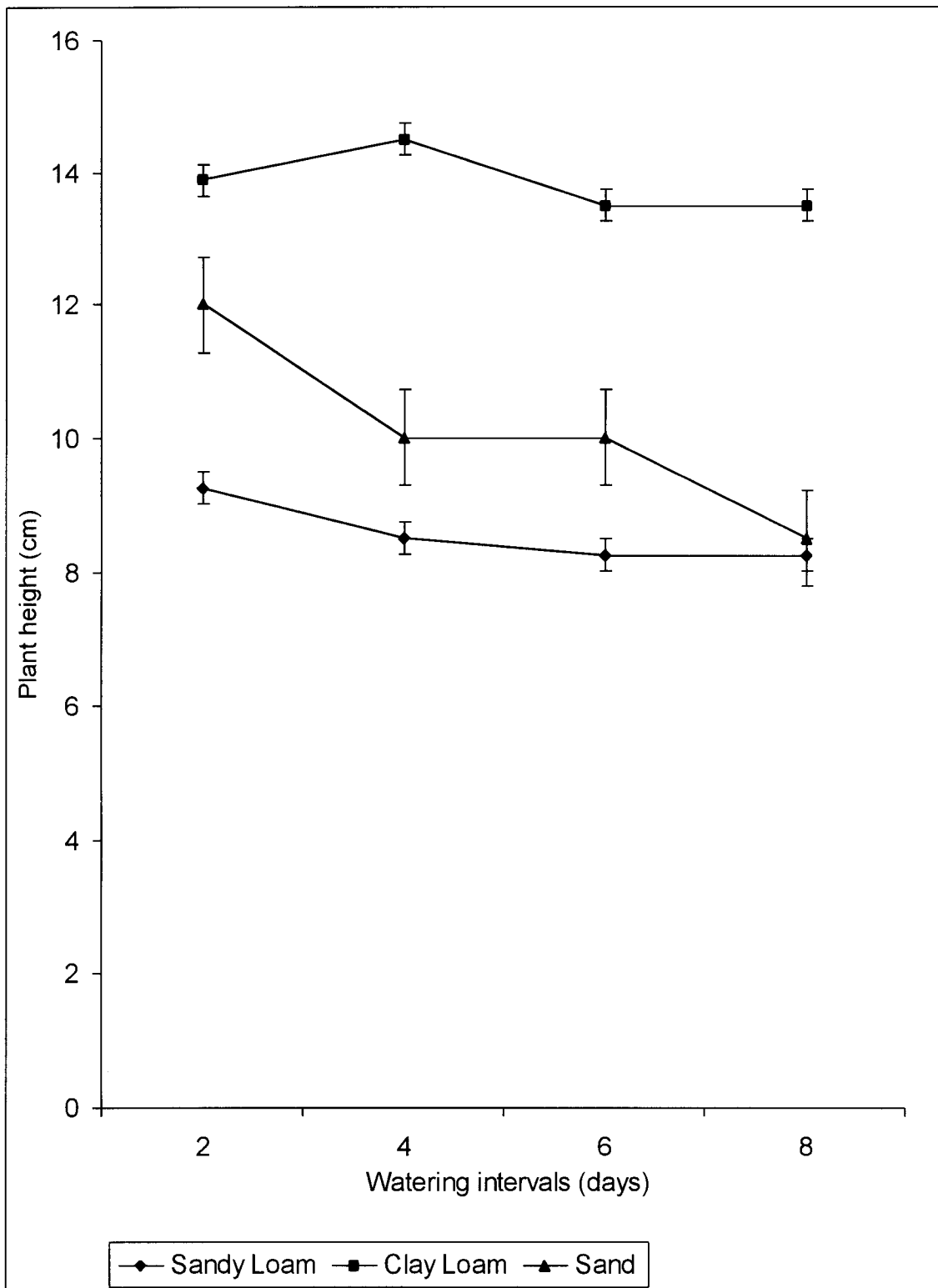


Figure 2. Effect of watering interval on shoot height in different soils at 28 DAP.

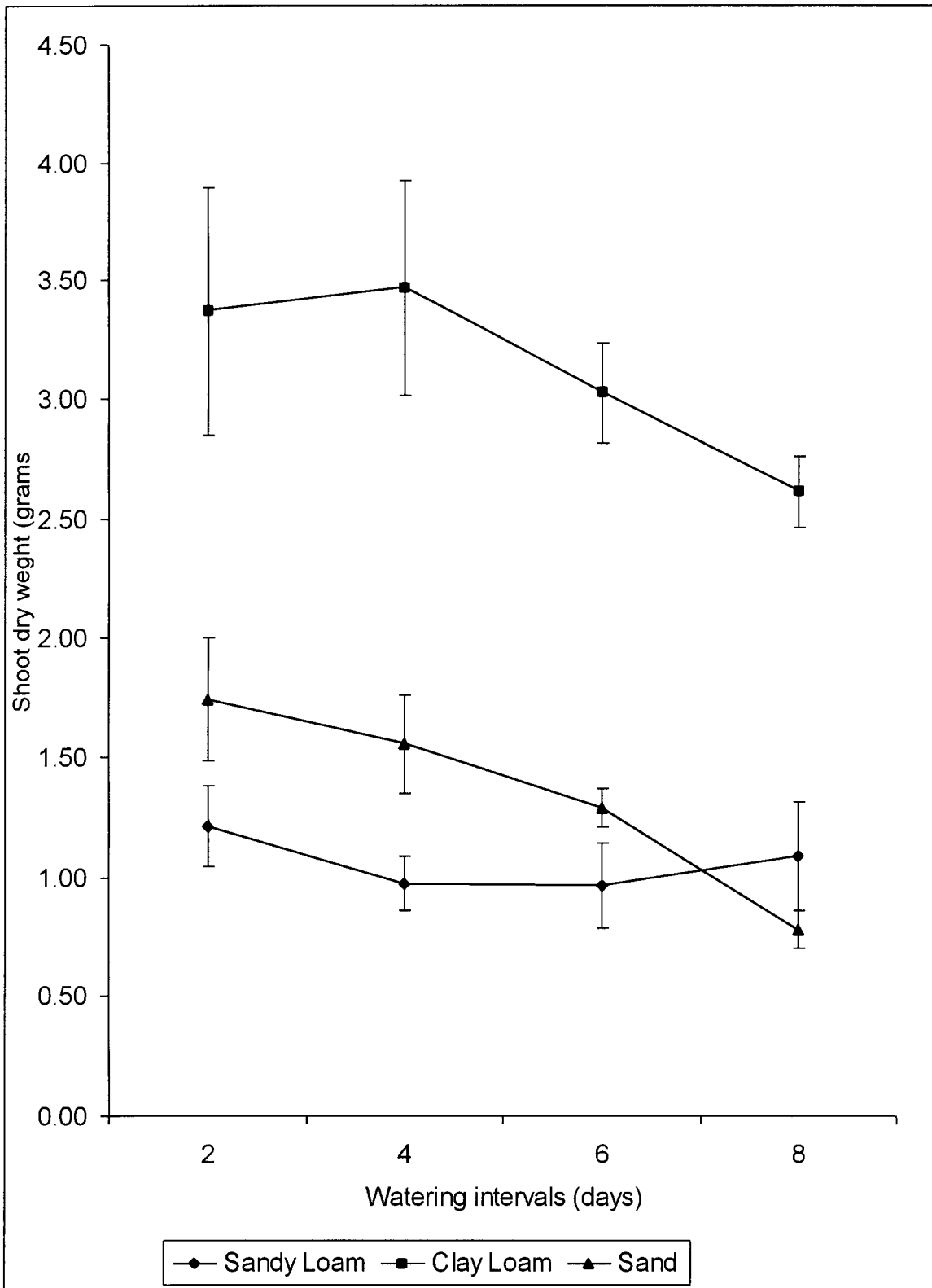


Figure 3. Effect of watering interval on shoot dry weight in different soils at 28 DAP.

## Experiment 2. Effects of planting depth on sorghum emergence.

Data in Table 2 show that high seedling emergence percentage was obtained at the 3-cm planting depth in all soils. The average seedling emergence percentage at 3, 6, 9, 12 and 15 DAP at different planting depths within each soil type decreased with increasing planting depth. It was 96% in sandy loam, and 98% in both clay loam and sand at 6 DAP, as compared to 19% in the sandy loam, 25% in the clay loam, and 44% in the sand soil at the 6-cm planting depth. At 9-cm planting depth, no emergence was recorded at 6 DAP (Figure 4).

**Table 2. Seedling emergence percentage at 3 planting depths in sandy loam, clay loam and sand soils over time after planting.**

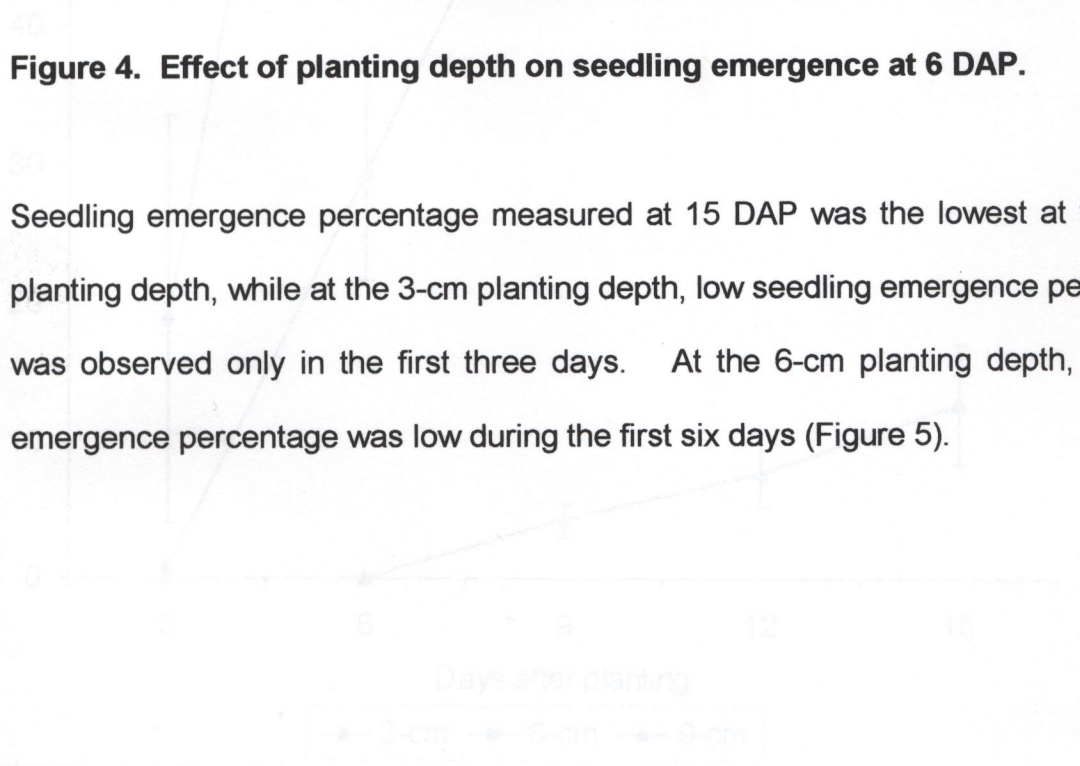
Soil Type	Planting Depth (cm)	Days after planting (DAP)				
		3	6	9	12	15
Sandy Loam	3	8.35	95.84	95.84	95.84	95.84
	6	2.08	18.75	68.75	70.84	70.84
	9	0.00	00.00	6.25	12.50	14.50
Clay Loam	3	0.00	97.92	97.92	97.92	100.00
	6	0.00	25.00	52.08	52.00	54.08
	9	0.00	00.00	4.17	6.25	18.75
Sand	3	47.84	97.92	97.92	97.92	97.92
	6	0.00	43.75	54.66	67.71	70.83
	9	0.00	0.00	2.08	4.17	4.17
Mean		6.47 c	42.13 b	55.09 a	56.13 a	56.70a

Means in the same row followed by common letter are not significantly different at 1% probability level using Duncan's Multiple Range Test.



**Figure 4. Effect of planting depth on seedling emergence at 6 DAP.**

Seedling emergence percentage measured at 15 DAP was the lowest at the 9-cm planting depth, while at the 3-cm planting depth, low seedling emergence percentage was observed only in the first three days. At the 6-cm planting depth, seedling emergence percentage was low during the first six days (Figure 5).



**Figure 5. Seedling emergence percentage as affected by planting depth over time after planting.**

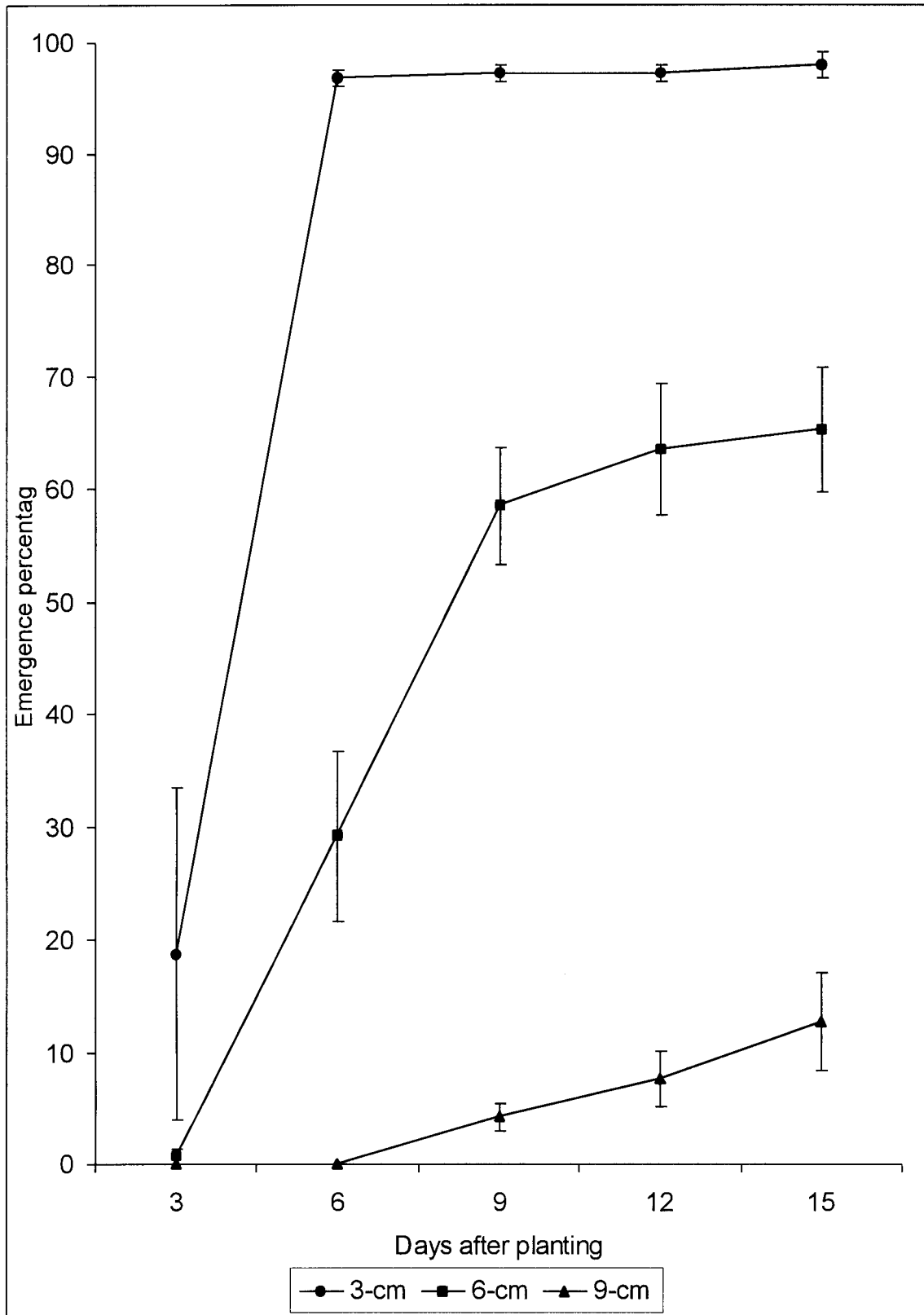


Figure 5. Seedling emergence percentage as affected by planting depth over time after planting.

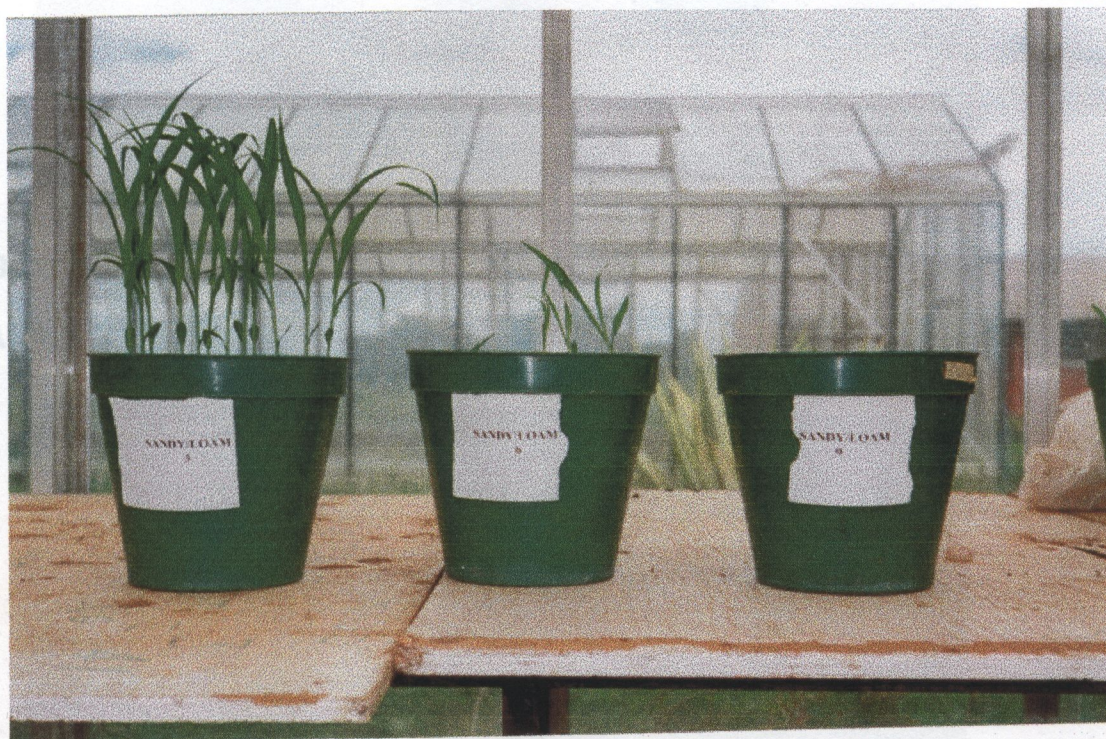
The results of the analysis of variance show highly significant effects of planting depth on the sorghum emergence (Appendices 5 and 6). Results of the analysis of variance also show a significant interaction ( $P \leq 0.01$ ) between planting depth and DAP, indicating that seedling emergence at different planting depths differed with days (Appendix 5). Emergence percentage at 9 to 15 DAP from 6 and 9-cm planting depths was significantly ( $P \leq 0.01$ ) lower than that measured at the 3-cm planting depth. There were significant differences in the total seedling emergence for the different planting depths in all the soils (Table 3). At 15 DAP seedling emergence at 3-cm depth was almost 100% in all soils 65 % at the 6-cm planting depth and only 12 % at the 9-cm planting depth (Figure 5). The data show that the total seedling emergence percentage decreased with increasing planting depth.

**Table 3. Total seedling emergence percentage in three soil types as affected by planting depth at 15 days after planting.**

Soil types	Planting depths (cm)			Mean
	3	6	9	
Sandy Loam	95.84	70.84	14.50	60.39
Clay Loam	100.00	54.08	18.75	57.64
Sand	97.92	70.83	4.17	57.84
<b>Mean</b>	97.92 a	65.25 b	12.47 c	

Means in the same row followed by the same letter are not significantly different at 1% probability level using Duncan's multiple Range Test.

At 15 DAP differences in shoot height from the three planting depths were evident (Figures 6, 7, 8). However, at 28 DAP there were no significant differences between the 3-cm and 6-cm planting depths. A similar trend was observed in shoot dry weight, which decreased for plants placed deeper than 3 cm, with a significant decrease at the 9-cm planting depth. Seedlings from the 3-cm planting depth had almost 3 times the mass of seedlings from the 9-cm planting depth (Table 4).



**Figure 6. Shoot development from sandy loam soil at three planting depths at 15 DAP.**

Figure 8. Shoot development from sand soil at three planting depths at 15 DAP.



Experiment 3. Effect of raindrop impact on soil crust strength and sorghum emergence.  
**Figure 7. Shoot development from clay loam soil at three planting depths at 15 DAP.**



**Figure 8. Shoot development from sand soil at three planting depths at 15 DAP.**

**Table 4. Effect of planting depth on shoot height and shoot dry weight.**

Planting Depth (cm)	Shoot height (cm)	Shoot dry weight (g)
3	18.00	0.82
6	16.50	0.75
9	6.75	0.28
LSD (0.05) =	4.34	0.28

### **Experiment 3. Effect of raindrop impact on soil crust strength and sorghum emergence.**

The data in Table 5 show penetrometer readings on different soils as affected by different water drop sizes. Penetration resistance was high during the first 6 days after planting, but it declined with time. Penetrometer readings showed no significant differences among water drop sizes, but there were significant differences ( $P \leq 0.05$ ), in readings between the different soils. Clay loam had the highest penetration resistance readings ( $3.50 \text{ kg.cm}^{-2}$ ), sandy loam ( $1.54 \text{ kg.cm}^{-2}$ ), and sand soil offered the least resistance ( $0.90 \text{ kg.cm}^{-2}$ ). Modulus of rupture readings also followed the same trend. Sand and sandy loam had the lowest readings ( $0.01 \text{ N.cm}^{-2}$ ) and clay loam gave  $0.04 \text{ N.cm}^{-2}$ .

**Table 5. Mechanical resistance of the three soil types with time following raindrop impact (Penetrometer readings,  $\text{kg.cm}^{-2}$ ).**

Soil type	Drop size	Days after			
		6	9	12	Mean
Sandy loam	Large (5 mm)	1.94	1.56	1.56	1.69
Clay loam	"	3.31	2.50	2.31	2.71
Sand	"	1.06	0.94	0.69	0.90
Sandy loam	Medium (4 mm)	1.69	1.63	1.44	1.59
Clay loam	"	3.25	2.50	2.69	2.81
Sand	"	1.38	0.88	0.44	0.90
Sandy loam	Small (3 mm)	1.44	1.44	0.94	1.28
Clay loam	"	2.88	2.50	2.50	2.63
Sand	"	0.75	0.88	0.63	0.75
<b>Mean</b>		1.97	1.65	1.47	

LSD (0.05) = 0.31  $\text{kg. cm}^{-2}$

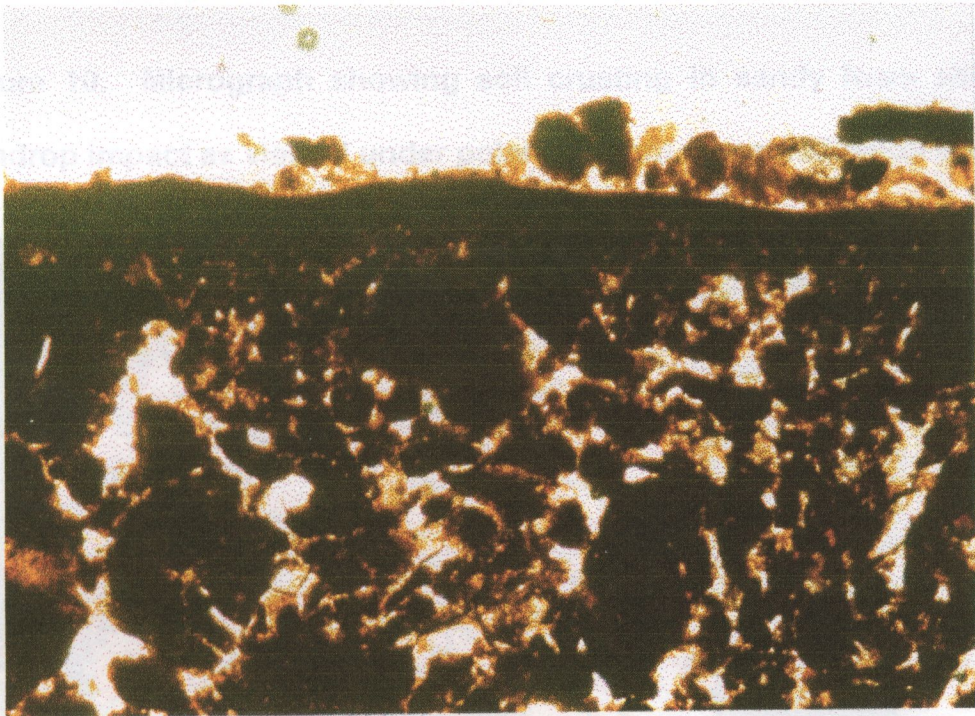
Examination of soil thin sections through the microscope revealed that the thickness of the crust and surface seal in clay loam was greater than for both sandy loam and sand soil (Figure 9). The thickness of the surface seal in clay loam ranged from 0.1mm to 1mm and the crust averaged 1 mm. The crusted layer was very dense and thick. However, the layer just below the crust was also compacted, having closely packed soil aggregates although less dense than the layer above it.

Below these layers, the soil aggregates were larger than in the first two layers.

The sandy loam soil had a surface seal thickness of 0.1-0.2 mm. The crust had closely packed soil particles of higher density than the ones below it (Figure 10).

The sand soil had four distinct layers of re-arranged particles. The surface seal consisted of dense closely packed soil particles, measuring from 0.4 to 1 mm in thickness. The layer below was less dense, but thicker than the layer above. This was followed by another dense layer that was crusted but thinner than the first layer.

The soil particles just below the crusted layers were much smaller than the ones further away from the crusted layers. Large sand grains could be clearly seen (Figure 11).



**Figure 9. Micrograph showing soil crusting in clay loam soil following raindrop impact as viewed under polarised light at magnification x 25.**

**Figure 11. Micrograph showing soil crusting in sand soil following raindrop impact as viewed under polarised light at magnification x 25.**

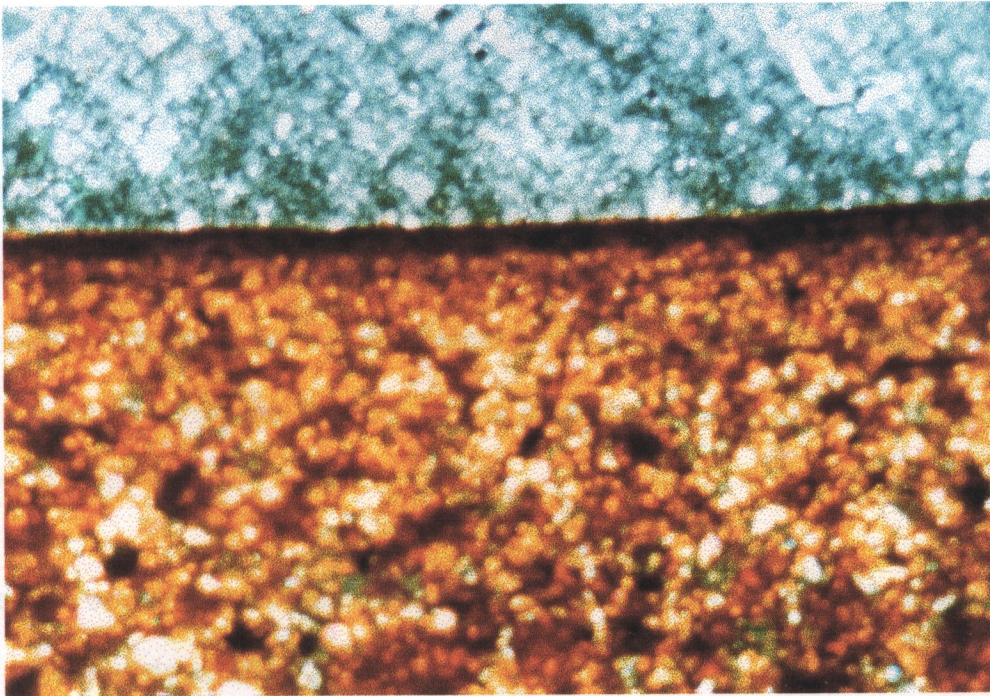


Figure 10. Micrograph showing soil crusting in sandy loam soil following raindrop impact as viewed under polarised light at magnification x 25.

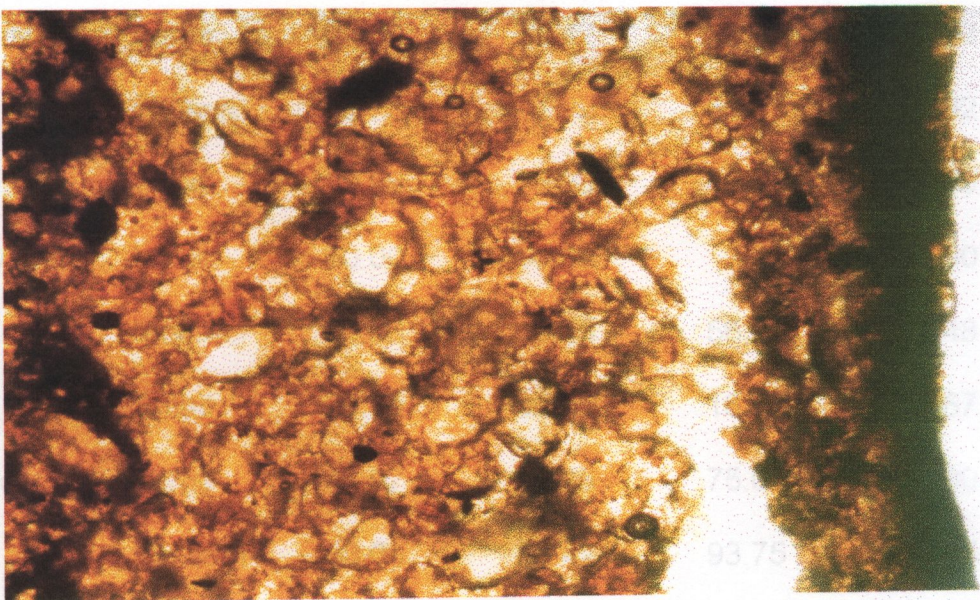


Figure 11. Micrograph showing soil crusting in sand soil following raindrop impact as viewed under polarised light at magnification x 25.

The percentage emergence data at 7 DAP through 15 DAP measured at 2 day intervals are presented in Table 6. Water drop size had no significant effect on seedling emergence. Nonetheless, a large drop size induced lowest emergence percentage while medium and small drop sizes had the highest emergence percentage. The order of seedling emergence from all soils at 15 DAP was 79.87% for the medium drop size, 72.92% for the small drop size and 65.70 % for large drop size (Appendix 14).

**Table 6. Percentage seedling emergence as influenced by soil type, water drop size and days after planting.**

Soil types	Drop size	Days after planting				
		7	9	11	13	15
Sandy loam	Large	20.80	35.42	75.42	83.33	85.42
	Medium	18.75	47.92	66.67	74.92	77.09
	Small	39.59	75.00	83.34	87.50	87.50
Clay loam	Large	00.00	00.00	2.00	25.00	37.50
	Medium	00.00	6.25	56.25	64.48	8.75
	Small	00.00	00.00	18.75	41.67	8.34
Sand	Large	41.67	56.25	75.00	75.00	75.00
	Medium	50.00	60.42	93.75	93.75	93.75
	Small	50.00	64.58	72.92	72.92	72.92
<b>Mean</b>		24.54 d	38.43 c	60.42 b	68.74a	72.92a

Means in the same row followed by a common letter are not significantly different at 1% probability level using Duncan's Multiple Range Test.

Seedling emergence varied with soil type, and crust strength varied significantly ( $P \leq 0.01$ ) with soil type. Emergence percentage from the clay loam soil was significantly lower than that from the sand and sandy loam soils (Figure 12). At 15 DAP, 83% emergence was recorded from the sandy loam soil, 80% from sand soil and 54% from clay loam.

Results of the analysis of variance showed a significant interaction between soil types and days after planting (Appendix 9). The data show that seedling emergence percentage on different days was not the same among the soil types. By the 7 DAP, no emergence was recorded from the clay loam soil for all drop sizes, whereas almost 50% emergence was recorded in sand soil and 25% in the sandy loam soil (Figure 12).

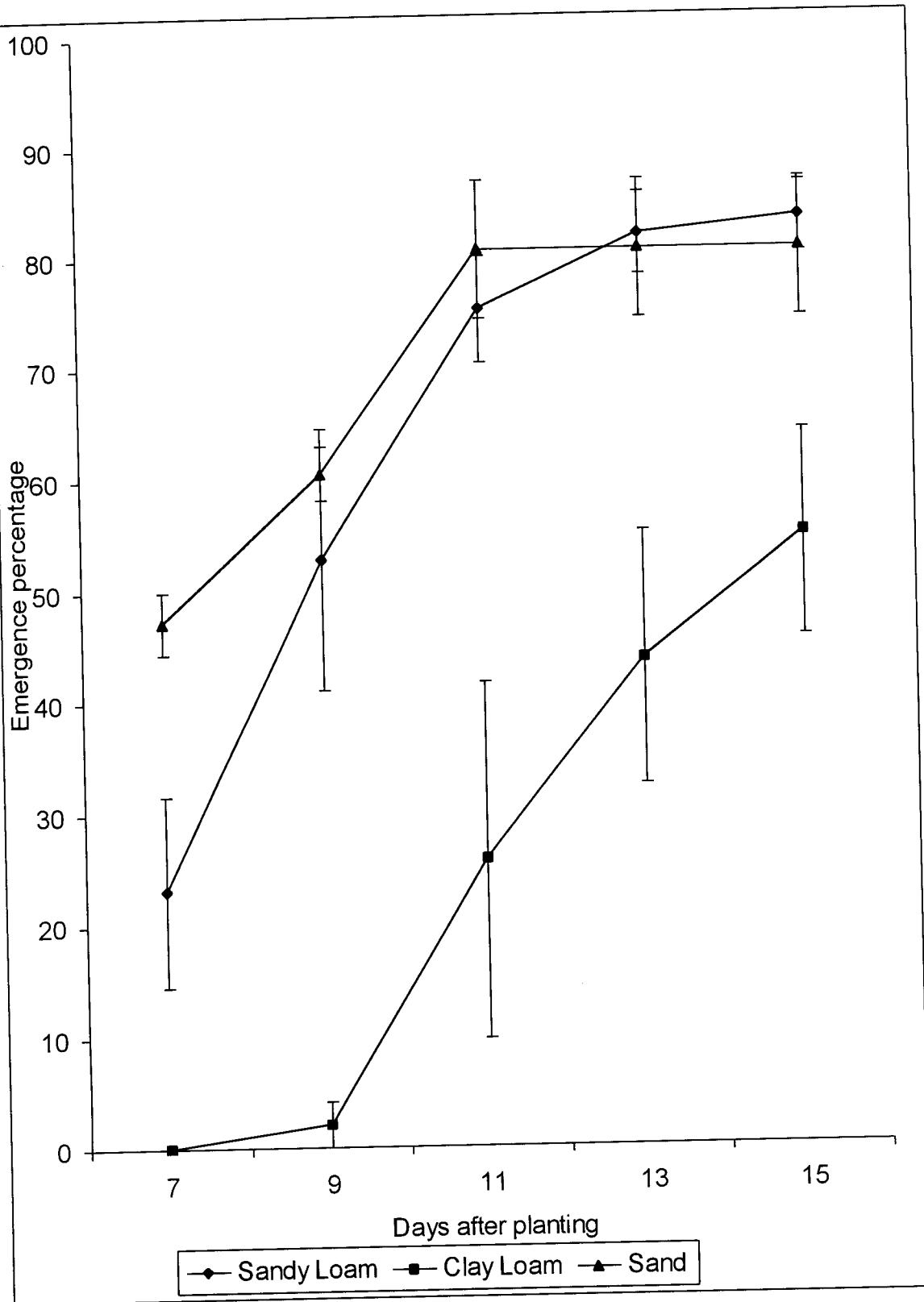


Figure 12. Seedling emergence percentage over time from three soil types following raindrop impact.

Seedling growth characteristics were significantly different among the soil types.

Shoot height from clay loam soil was significantly ( $P \leq 0.01$ ) lower than from both sand and sandy loam. Shoot dry weights, were, however, similar for clay loam and sandy loam but significantly ( $P \leq 0.01$ ) lower than from sand soil (Table 7).

**Table 7. Shoot height and shoot dry weight as affected by soil type and drop size at 28 DAP.**

Soil Types	<u>Shoot height (cm) at 28 DAP.</u>			Mean
	Large	Medium	Small	
Sandy loam	6.00	7.50	7.50	7.08
Clay loam	2.50	5.00	5.50	4.33
Sand	11.50	10.75	9.75	10.67

LSD (0.05) = 1.88 cm

Soil Types	<u>Shoot dry weight (g) at 28 DAP.</u>			Mean
	Large	Medium	Small	
Sandy loam.	0.13	0.11	0.17	0.13
Clay loam	0.01	0.11	0.07	0.07
Sand	0.33	0.33	0.23	0.30

LSD (0.05) = 0.10 g.

Crust strength was negatively and significantly ( $P \leq 0.01$ ) correlated with seedling emergence ( $r = -0.620^{**}$ ) across all soil types. Water drop size was positively correlated with crust strength but it was not significant (Table 8).

Crust strength in sand and sandy loam soils was significantly and negatively correlated with emergence. In clay loam soil the correlation between crust strength and emergence was negative though not significant (Appendices 15,16,17). The seedling growth characteristics were all negatively and significantly ( $P \leq 0.01$ ) correlated with crust strength, and were significantly different among soil types.

**Table 8. Correlation between different measured plant parameters across soil types.**

	Drop size	Crust strength	SHT	SDWT
Drop size	-			
Crust strength	0.08 <sup>ns</sup>	-		
Emergence	-0.12 <sup>ns</sup>	-0.63 <sup>**</sup>		
SHT	-0.07 <sup>ns</sup>	-0.72 <sup>**</sup>	-	
SDWT	-0.03 <sup>ns</sup>	-0.61 <sup>**</sup>	0.81 <sup>**</sup>	

SHT=Shoot height, SDWT= Shoot dry weight, <sup>ns</sup>=non significant, \*=significant at 5% probability level, \*\*=significant at 1% probability level.

## 5.0. DISCUSSION

The emergence of sorghum seedlings was not significantly ( $P \leq 0.05$ ) affected by watering intervals in all soil types. For the watering intervals not to result in significant differences in seedling emergence may suggest that the crop is less sensitive to moisture stress during emergence provided initial moisture is relatively adequate. As reported by Heatherly and Russel (1979), other work has shown little or no change in emergence rates of sorghum when soil water potentials were  $-4$  bars or greater. This confirms that sorghum emergence is not adversely affected by low moisture levels except in extreme cases.

However, significant effects of watering intervals were observed on seedling growth characteristics. Seedling growth characteristics showed some response to the watering intervals. Shoot height was reduced in the 8-day watering interval, especially in the sandy loam soil and sand soil with less reduction in the clay loam soil compared to the other two soil types. Similarly, shoot dry weight decreased with increasing watering intervals, significantly at the 8-day watering interval, with significant differences among the soils. This result could be due to the higher water-holding capacity of clay loam than both sandy loam and sand (Table 1). The sandy loam and sand soils showed greater reduction in shoot dry weight than the clay loam soil. Nevertheless, all soil types had lower shoot dry weight in the 8-day watering interval. In the 8-day watering interval, the sand soil had the lowest shoot dry mass, probably indicating that more days without rainfall may affect the crop growing on the sand more than on sandy loam and the clay loam soils.

The significant high dry mass and shoot height on clay loam soil show that the clay loam soil may be a suitable soil type for good sorghum emergence and seedling establishment in dry areas. This is so, provided soil moisture is relatively adequate in the first ten days after planting, which is however rarely the case. According to Lyles and Fanning (1964), the decrease in sorghum emergence was only observed at the water tension of 8 bars. It is therefore likely that the erratic rainfall in Lusitu is relatively enough for emergence and seedling establishment, more especially because farmers plant after the first rains.

There were significant differences in seedling emergence at the three planting depths. Seedling emergence was greater at the 3-cm planting depth and lowest at the 9-cm planting depth for all soils. The planting depth experiment has shown that the sorghum variety used in the experiment can emerge satisfactorily when planted at 3-cm depth in the three soil types used in this experiment, and other soils similar to them in physical properties. Seedling emergence was significantly ( $P \leq 0.01$ ) reduced with increased depth of planting in all the soils. Cardwell (1984) reported that the common maximum depth for emergence of sorghum is between 7.5 to 12-cm. In contrast, the results of this study show that planting sorghum deeper than 6-cm results in poor to zero emergence. Emergence was reduced by as much as 34% at the 6-cm planting depth and by almost 90% at the 9-cm planting depth. These results suggest that sorghum can successfully emerge from shallow planting depth which has also been previously reported (Stoskopf, 1985; Rowland and White, 1993).

The adverse effects of deep planting on emergence can be either partial when emergence is only delayed, or total when the seedlings fail to emerge. The data demonstrate that planting deeper than 6 cm can cause poor, or delayed emergence. Emergence was delayed by about 6 days in the experiment reported here. This delay would mean a very poor crop stand in the field. Delayed emergence is not entirely better than no emergence at all because seedlings in delayed emergence are exposed to adverse conditions such as soil moisture stress and diseases.

These observed effects of depth of planting on emergence, shoot length, and shoot dry weight indicate that deep planting in general results in reduced emergence and poor stand establishment. Deep planting seems to be one of the causes of poor sorghum seedling emergence and establishment. Therefore, farmers in Lusitu who dribble seed into a plough furrow, or make a hole with a hoe and plant seeds in these holes, may fail to get good emergence from such unknown planting depths which are likely to be deeper than 6 cm. Furthermore, farmers may deliberately choose to plant deeper in dry areas like Lusitu in order to avoid seed desiccation at shallower depths in dry weather.

In the experiment to evaluate impact of raindrop size on seedling emergence, the clay loam soil had the lowest seedling emergence among the three soils, consistent with the high resistance to penetration and high modulus of rupture readings. Seedlings were unable to break through the soil surface and needed to exert high pressure to break through the crust. Consequently, there was either partial or total failure of seedling emergence.

Greater seedling emergence was observed on the sandy loam and sand soils than on the clay loam soil irrespective of the water drop size. These results are consistent with those of Painuli and Abrol (1986) who concluded that soil crusting increases resistance to shoot penetration, leading to poor stand establishment on fine textured soils, and that seedling emergence through the crust is controlled by crust strength. This was also the observation by the farmers in Lusitu who reported that seedling emergence from clay loam is a problem if planting is followed by a dry period.

In clay loam soil the aggregates on the soil surface slake during water application. Subsequent drying leads to greater particle to particle contacts and more particle bonding, resulting in formation of hard crusts which reduce seedling emergence. Glanville and Smith (1988) have stated that crusting is more pronounced in clay loam soils due to the colloidal clay particles sealing the surface after being disaggregated by the impact of the raindrops. This is confirmed in this study where examination of soil thin sections showed thick and dense surface crusts. The high modulus of rupture readings for clay loam also indicate that in a clay loam soil greater pressure is required than in either sand soil or sandy loam soil for the seedlings to emerge through the crust. There was reduced seedling emergence observed with large water-drop (5 mm). However, this result was not statistically significant from small (3 mm) and medium (4 mm) water drop sizes. According to Sivaprasad and Sarma (1987), this observation can be attributed to the fact that large raindrops enhance soil compaction at the soil surface because of greater soil aggregate destruction.

Soil crusting is critical especially for the small sorghum seed size (diameter of 2.9 mm to 3.3 mm per seed.) because of the relatively small penetration strengths of their seedlings. Seedlings emergence from these soils is consistent with the observed crust formation and crust strength, which in increasing order were clay loam, sandy loam and sand.

As shown by high crust strengths obtained from clay loam, it means that the seedlings need to have more penetration strength to push through the crust. This observation is further confirmed by the microscope examination of soil thin sections showing the varying thickness of the crusts formed on these soils. The crusts in clay loam soil are very thick and dense (Figure 9). Furthermore, the soil aggregates below the crusts are big which would make it difficult for the coleoptile to go through during emergence. The seedlings can only go through the cracks between the soil separates, but they will encounter resistance in going through the crust formed at the surface. Although the sand soil has a thicker crust (Figure 11) than the sandy loam soil (Figure 10), but the crust strength is weak, requiring only minimal force to break. As a result, the seedlings do not require much penetration strength to go through such crust.

These results show that areas such as Lusitu which experience dry spells during the growing season are likely to have poor sorghum seedling emergence and stand establishment because of crusting in clayey soils. The occurrence of high temperatures following rainfall, which is experienced in Lusitu, may also lead to high moisture evaporation from the soil surface, leading to crust formation.

## 6.0. CONCLUSIONS

Poor sorghum seedling emergence and stand establishment in soils from Lusitu can be attributed to deeper planting in all soils and to soil crusting especially in clay loam soils. Maintenance of optimum planting depth is an important factor for consideration in order to achieve maximum sorghum seedling emergence and establishment. Deep planting can lead to poor crop stand while shallow planting can result in better crop stands. Planting sorghum at not any deeper than 3 cm produced high seedling emergence percentage (98%). This result means that a crop can establish well and quickly avoiding hazards such as moisture stress and diseases during early establishment. Shoot dry weight and shoot height were also greater when the crop was planted at 3 cm depth, and this might be advantageous for early establishment of sorghum.

Watering intervals did not affect seedling emergence in all three soil types. This result suggests that soil moisture may not be a problem as far as seedling emergence is concerned because the soil and seeds were kept moist long enough during emergence. However, shoot dry weight was reduced at the 8-day watering interval, suggesting that moisture stress can adversely affect the growth of sorghum seedlings.

Raindrop impact on soil adversely affects seedling emergence in heavy textured soils such as clay loam because of the thicker and stronger crust that forms on the soil surface than in sandy loam and sand.

Soil crusting leads to poor and delayed seedling emergence. For seedling emergence to be improved in clay loam, there should be regular rainfall to soften the crust, and therefore the problem can be alleviated by irrigation. High soil drying rates lead to formation of hard crusts in this soil, which inhibit seedling growth. In this situation, seedlings can only grow through cracks. The soil thin section data on the magnitude of crusting has also indicated that the crusts are very thick and dense in clay loam soil. The soil aggregates below the crust are also large making it further difficult for the penetrating shoot to lift such coherent and dense soil masses during emergence.

Based upon the results of this glasshouse study, rapid and uniform emergence and proper seedling development of sorghum can be expected if planting depth is approximately 3 cm and there is no soil crusting. The importance of depth of planting is clearly highlighted by this study. Planting at 3-cm planting depth in all soils is highly recommended. The improvement of planting methods such as use of ox-drawn planters, whereby a correct planting depth is maintained would improve emergence of the crop.

The application of manure can improve the physical properties of the soils by reducing high crust strengths and increasing moisture retention capacity. Crust formation can be minimised by maintaining soil cover to minimise the impact of raindrops. The soil cover would reduce disaggregation and build up organic matter over the long term to increase aggregation. In addition, light tillage while the soil is still moist will break up the crust before it hardens.

## 7. 0. RECOMMENDATIONS

In the study to investigate the effect of watering intervals on sorghum emergence and seedling establishment, emphasis was on comparing watering intervals, and amount of water in the soils was maintained at half the moisture content of soil held at field capacity. There is need to investigate the optimum soil water potentials for sorghum seedling emergence from these soils. More effort should be directed at studying seedling emergence under various soil water potentials. It is also important to research alternative methods of seedbed preparation in order to determine how best seedbeds can be managed in order to reduce surface crusting and increase seedling emergence.

It is difficult to ensure uniform optimum planting depth (3 cm) under small-scale farmer conditions using conventional cultural practices with a hand hoe, or planting behind the plough. There is need, therefore, to research and design simple tools that will ensure uniform optimum planting depth. In farming systems where farmers are accustomed to using ox-drawn implements, there is need to train farmers to adjust their implements for planting seeds at recommended depths.

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## 9.0. APPENDICES

**Appendix 1. ANOVA Table: Effect of watering intervals, soil type and days after planting on seedling emergence percentage.**

Source	df	SSQ	MSQ	F- Cal	F-Tab (5%)
Replication	3	2478.91	826.30	10.26	
W. interval	3	256.03	85.35	1.06 <sup>ns</sup>	3.86
Error	9	725.05	80.56		
Soil type	2	283.61	141.80	1.99 <sup>ns</sup>	5.14
Error	6	427.74	71.29		
Interval x soil	6	119.10	19.99	0.24 <sup>ns</sup>	3.66
Error	18	1473.59	81.87		
DAP	3	17171.40	5723.80	108.53 <sup>**</sup>	2.68
Interval x DAP	9	347.88	38.65	0.73 <sup>ns</sup>	
Soil x DAP	6	2423.41	403.90	7.66 <sup>**</sup>	2.17
Soil x DAP x Int	18	365.24	20.29	0.38 <sup>ns</sup>	1.68
Error	108	95.80	52.74		

CV% = 10.04

\*= Significant at 5% probability level

\*\*= Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 2. ANOVA Table: Total seedling emergence percentage at 10 DAP  
as affected by watering intervals and soil type.**

Source	df	SSQ	MSQ	F- Cal	F-Tab (5%)
Replication	3	107.42	35.81	1.22	
W.interval	3	94.40	31.47	1.07 <sup>ns</sup>	3.86
Error	9	263.67	29.30		
Soil type	2	148.11	74.06	2.60 <sup>ns</sup>	5.14
Error	6	170.90	28.48		
W x Soil	6	47.20	7.87	0.34 <sup>ns</sup>	3.66
Error	18	415.04	23.06		

CV=5.02%

<sup>ns</sup> = non significant

**Appendix 3. ANOVA Table: Shoot height as affected by watering interval and soil type.**

Source	df	SSQ	MSQ	F-Cal	F-Tab (5%)
Replication	3	9.51	3.17	1.17	
W.interval	3	17.47	5.82	2.16 <sup>ns</sup>	3.86
Error	9	24.29	2.70		
Soil type	2	197.61	98.80	46.84 <sup>**</sup>	5.14
Error	6	12.66	2.11		
W x Soil	6	15.14	2.52	0.95 <sup>ns</sup>	3.66
Error	18	47.86	2.66		

CV% 14.80

<sup>\*\*</sup>=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 4. ANOVA Table: Shoot dry weight as affected by watering interval and soil type.**

Source	df	SSQ	MSQ	F-Cal	F-Tab(5%)
Replication	3	3.37	1.12	4.79	
W. interval	3	2.69	0.10	3.83 <sup>ns</sup>	3.86
Error	9	2.11	0.23		
Soil type	2	39.92	19.96	110.53**	5.14
Error	6	1.08	0.18		
W x Soil	6	1.38	0.23	1.45 <sup>ns</sup>	3.66
Error	18	2.86	0.16		

CV%=21.64

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 5. ANOVA Table: Seedling emergence percentage as affected by soil type planting depth and days after planting.**

Source	df	SSQ	MSQ	F-Cal	F-Tab (5%)
Replication	3	2727.09	909.03	1.12	
Soil type	2	1405.33	702.66	0.86 <sup>ns</sup>	3.40
Planting depth	2	76332.97	38166.48	46.83**	3.40
Planting depth x soil type	4	891.08	222.77	0.27 <sup>ns</sup>	2.78
Error	24	19559.59	814.98		
DAP	4	31898.78	7974.70	55.56**	2.44
Soil type x DAP	8	1916.34	39.54	1.67 <sup>ns</sup>	2.01
Planting depth x DAP	8	15673.51	1959.19	13.65**	2.01
Pla x soil x DAP	16	4452.12	278.25	1.94*	1.72
Error	108	15501.98	143.54		

CV%=29.06

\*= Significant at 5% probability level

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 6. ANOVA Table: Seedling emergence percentage at 15 DAP as affected by soil type and planting depth.**

Source	df	SSQ	MSQ	F-cal	F-Tab (5%)
Rep	3	294.85	98.29	0.46	
Soil type	2	13.14	6.57	0.03 <sup>ns</sup>	3.40
Planting Depth	2	22619.15	11309.58	53.43 <sup>**</sup>	3.40
Soil x planting depth <sup>4</sup>		696.68	174.17	0.82 <sup>ns</sup>	2.78
Error	24	5080.01	211.67		

CV% = 28.35

<sup>\*\*</sup>=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 7. ANOVA Table: Shoot height as affected by soil type and planting depth.**

<b>Source</b>	<b>df</b>	<b>SSQ</b>	<b>MSQ</b>	<b>F-Cal</b>	<b>F-Tab (5%)</b>
Rep	3	59.42	19.81	0.71	
Soil type	2	43.17	21.58	0.82 <sup>ns</sup>	3.40
Planting depth	2	895.50	447.75	15.96 <sup>**</sup>	3.40
Soil x depth	4	199.33	49.83	1.88 <sup>ns</sup>	2.78
Error	24	635.33	26.47		

CV%=37.42

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 8. ANOVA Table: Shoot dry weight as affected by soil type and Planting depth.**

Source	df	SSQ	MSQ	F-Cal	F-Tab (5%)
Rep	3	0.75	0.25	2.22	
Soil type	2	0.14	0.07	0.64 <sup>ns</sup>	3.40
Planting depth	2	2.12	1.06	9.37 <sup>**</sup>	3.40
Soil x depth	4	0.66	0.17	1.46 <sup>ns</sup>	2.78
Error	24	2.71	0.11		

CV%=54.30

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 9. ANOVA Table: Effect of soil type, drop size and days after planting on seedling emergence percentage.**

Source	df	SSQ	MSQ	F-cal	F-Tab (5%)
Replication	3	13656.65	4552.22	7.75	
Soil type	2	35144.27	17572.13	29.88**	3.40
Drop size	2	2407.26	1203.63	2.05 <sup>ns</sup>	3.40
Soil x drop	4	4188.34	1047.10	1.78 <sup>ns</sup>	2.78
Error	24	14110.29	587.93		
DAP	4	30713.21	7678.30	59.57**	2.44
Soil x DAP	8	3438.23	429.78	3.33*	2.01
Drop x DAP	8	1276.12	159.51	1.24 <sup>ns</sup>	2.01
Drop x soil x DAP	16	2122.30	132.64	1.029 <sup>ns</sup>	1.72
Error	108	13920.34	128.89		

CV%=24.45

\*= Significant at 5% probability level

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 10. ANOVA Table: Total seedling emergence percentage at 15 DAP  
as affected by soil type and drop size.**

Source	df	SSQ	MSQ	F-Cal	F-Tab(5%)
Replication	3	1738.28	579.43	2.43	
Drop size	2	603.20	301.60	1.26 <sup>ns</sup>	3.40
Soil type	2	2664.20	1332.10	5.84 <sup>**</sup>	3.40
Soil type x drop size	4	1056.20	264.05	1.11 <sup>ns</sup>	
Error	24	5725.45	238.56		

CV% = 25.58

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 11. ANOVA Table: Effect of soil type, drop size and days after planting on mechanical resistance of soils estimated by penetrometer readings.**

Source	df	SSQ	MSQ	F-Cal	F-Tab(5%)
Replication	3	4.90	1.63	4.56	
Soil type	2	64.53	32.26	90.11**	3.11
Drop size	2	1.11	0.55	1.55 <sup>ns</sup>	3.11
Soil x drop	4	0.40	0.10	0.29 <sup>ns</sup>	2.48
DAP	2	4.62	2.31	6.45**	3.11
Soil x DAP	4	0.10	0.25	0.70 <sup>ns</sup>	2.48
Drop x DAP	4	0.53	0.13	0.37 <sup>ns</sup>	2.48
Drop x soil x DAP	8	1.06	0.13	0.37 <sup>ns</sup>	2.05
Error	78	27.93	0.36		

CV%=35.36%

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 12. ANOVA Table: Shoot height as affected by soil type and drop size.**

Source	df	SSQ	MSQ	F-Cal	F-Tab (5%)
Rep	3	94.97	31.66	6.37	
Soil type	2	242.06	121.03	24.35**	3.40
Drop Size	2	8.72	4.36	0.88 <sup>ns</sup>	3.40
Soil type x drop size	4	25.28	6.32	1.27 <sup>ns</sup>	2.78
Error	24	119.28	4.97		

CV%=30.29

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 13. ANOVA Table: Shoot dry weight as affected by soil type and drop size.**

Source	df	SSQ	MSQ	F- Cal	F-Tab (5%)
Rep	3	0.11	0.040	2.78	
Soil type	2	0.34	0.170	13.55**	3.40
Drop size	2	0.01	0.003	0.24 <sup>ns</sup>	3.40
Soil type x drop	4	0.05	0.010	0.94 <sup>ns</sup>	2.78
Error	24	0.30	0.010		

CV%= 67

\*\*=Significant at 1% probability level

<sup>ns</sup> = non significant

**Appendix 14. Total Seedling emergence percentage at 15 DAP as affected by soil type and drop size.**

Soil type	Drop sizes			Mean
	Large	Medium	Small	
Sandy Loam	85.42	77.10	87.50	83.34 a
Clay Loam	37.50	68.75	50.84	52.36 b
Sand	75.00	93.75	72.92	80.57 a
<b>Mean</b>	65.97	79.87	72.92	

Means in the same column followed by the common letter are not significantly different at 1% probability level using Duncan's Multiple Range Test.

### Appendix 15. Correlation between different parameters in sandy loam soil.

	Drop size	crust strength	emergence
Drop size	-		
Crust strength	0.283 <sup>ns</sup>	-	
Emergence	-0.217 <sup>ns</sup>	-0.376*	-

\*=Significant at 5% probability level

<sup>ns</sup> = non significant

**Appendix 16. Correlation between different parameters in clay loam soil.**

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	Drop size	crust strength	emergence
Drop size	-		
Crust strength	0.085 <sup>ns</sup>	-	
Emergence	-0.101	-0.128 <sup>ns</sup>	-

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<sup>ns</sup> = non significant

### Appendix.17. Correlation between different parameters in sand soil.

	Drop size	crust strength	emergence
Drop size	-		
Crust strength	0.14 <sup>ns</sup>	-	
Emergence	-0.087 <sup>ns</sup>	-0.608 <sup>**</sup>	-

\*\*=Significant at 1%  
<sup>ns</sup> = non significant