THE EFFECT OF CROP RESIDUE COVER AND SOIL TEXTURE ON CRUSTING

by

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DECLARATION

I hereby declare that this thesis submitted for the degree of Magister Scientiae Agriculturae at the University of the Orange Free State, is my own work and has not previously been submitted by me at another University. I furthermore cede copyright of the thesis in favor of the University of the Orange Free State.

Felicidade Isabel Massingue

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

THE EFFECT OF CROP RESIDUE COVER AND SOILTEXTURE ON CRUSTING

1. INTRODUCTION

Soil crusting or surface sealing is a phenomenon that has been studied throughout the world (Hoogmoed & Stroosnijder, 1984; Mando, 1997; Shainberg, 1992). The term crust refers to a thin layer at the soil surface formed by the impact of water either from rain or irrigation. Once the surface crust is formed it can have a prominent effect on soil behavior, for example, reduction of infiltration and increase in runoff, retarding the soil-atmosphere gas exchange, and causing a mechanical obstruction to emerging seedlings. The severity of the problem in a given soil depends primarily on the strength or hardness of the crust (Baver, Gardner & Gardner, 1972).

Studies in the laboratory and on the field investigated several methods for minimizing the adverse effects of soil crusts, such as the use of soil conditioners (Bennett, Ashley & Doss, 1964), tillage practices and planting methods (Cary & Evans, 1974) and the use of plant residues in the form of a mulch (Mehta & Prihar, 1973).

1.1 Soil crust formation

The formation of surface crusts on bare soils is a serious problem in many parts of the world (Moore, 1981). This problem is quite common in semi-arid and arid regions and occur on a variety of soils such as sandy loam, sandy clay, and sandy texture classes (Gupta & Yadav, 1978; Awadhwal & Thierstein, 1985). Soil susceptibility to surface crusting depends upon a combination of soil physical, chemical and biological processes which are affected by the prevailing climatic and soil conditions during the process of seal formation (Bradford & Huang, 1992).

A soil crust is a thin hard layer formed on the surface of the soil as a result of dispersive forces exerted by raindrops or irrigation water followed by drying. Crust formation involves two major complementary mechanisms, which can be summarized as follows:

1) Physical disintegration of soil-aggregates, caused by the impact of raindrops, reduces the average size of the pores of the surface layer. The impact of raindrops also causes compaction of the uppermost layer of the soil. These factors produce a thin skin seal at the soil surface (McIntyre, 1958; Onofiok & Singer, 1984).

2) Physicochemical dispersion of surface clay particles and subsequent illuviation of these particles into the region immediately beneath the surface, where these dispersed clay particles clog the pores and form an illuviated zone (Chen *et al.*, 1980; Agassi, Shainberg & Morin, 1981).

The surface crusts formed by mechanism (1) are called structural crusts whereas the ones formed by mechanism (2) are called depositional crusts (Shainberg & Singer, 1985). Soil crusts are characterized and distinguished by their higher mechanical strength, markedly low porosity, higher bulk density, lower degree of aggregation, higher amount of silt and clay and higher values of cation exchange capacity as compared to the underlying bulk soil (Hillel, 1980).

1.1.1 Effect of surface crusts on seedling emergence

Soil crusting has been listed by many workers as an important factor influencing seedling emergence (e.g. Richards, 1953; Hanks & Thorp, 1957). Seedling emergence in this study is referred to the plumule passing through the soil surface to emerge.

Emergence of seedlings may be limited by insufficient oxygen diffusion at the seed depth, limited water, or a high mechanical impedance of the surface crust. Seedling emergence is also a function of seedling size, vertical and horizontal placement (Arndt, 1965a). Seed weight and the emergence lifting force are closely correlated (Williams, 1956). For fine seedlings, frequent wide cracks in the soil crust are necessary for emergence. Monocotyledons with a point resistance are affected less than dicotyledons, which have to pull or push large appendages, the cotyledons, through the crust (Rathore, Ghildyal & Sachan, 1981). Some of the seeds usually affected by crusting are Pearl millet (*Pennisentum americanum* L.), cotton (*Gossypium hirsutum* L.), grain sorghum *(Sorghum bicolor* L.), soybean (*Glicine max* L.), carrot (*Daucus carota* L.), and cowpea (*Vigna unguiculata*) (Richards, 1953, Sale & Harrison, 1964; Chaudhry & Das, 1978, 1980; Gerard, 1980; Rathore, Ghildyal & Sachan, 1983).

Seedlings that emerged under crust conditions are smaller and weaker than seedlings that emerged normally (Sale & Harrison, 1964). When the emergence force developed by young seedlings is less than the resistance offered by the crust to penetration, the seedlings cannot push through the crust and bending or distortion of the seedlings takes place just beneath the crust. This horizontal growth of seedlings below crust results in delayed and reduced emergence (Arndt, 1965b).

Bennett *et al.* (1964) reported a negative linear relationship between the percentage of cotton emergence and crust strength. Joshi (1987) observed a similar relationship for pearl millet seedling emergence (Figure 1.1).

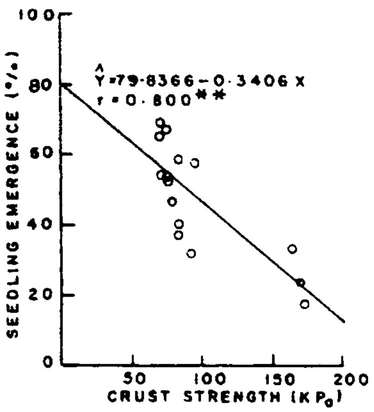

Figure 1.1: Influence of crust strength on the emergence of pearl millet seedlings (Joshi, 1987).

The seedling emergence – crust strength relationships for wheat in fine sandy loam, silt loam, and silt clay loam soils were found by Hanks & Thorp (1957) to be similar to those of grain sorghum and soybeans. Any increase in crust strength decreased seedling emergence of these crops but the rate of decrease was the highest at low crust strengths. Hanks & Thorp (1957) have also shown that wheat seedling emergence was not related to crust thickness or seedling spacing, but was highly correlated with crust strengths.

Crust strength is probably more important in it's effect on seedling emergence than crust thickness. For example, seedling emergence was less under a thin structural crust compared to a much thicker depositional crust (Arshad & Mermut, 1988). Farres (1978) found that the development of a thick crust protects deeper aggregates against dispersion.

The potential of crusts to inhibit seedling emergence was also studied by Miller, Truman & Langdale (1988). Three Cecil soils with varying degrees of erosion were planted to soybeans in small pans, wetted to field capacity and either exposed to rain or left without rain. The crust formed by the rainfall on the sandier (10 % clay), moderately well aggregated, and less dispersive soil had little effect on the measured modulus of rupture, penetration resistance and seedling emergence. Emergence was reduced on the soils exposed to rainfall, particularly the sandy loam with poor aggregation and higher dispersibility (12% clay) which had only 28 % emergence, a very high modulus of rupture and penetration resistance values. The sandy clay loam soil (25% clay) was intermediate, with increases in strength after rainfall associated with a certain reduced soybean emergence.

Bennett *et al.* (1964) demonstrated the severe crusting potential of a Greenville fine sandy loam from the Georgia Coastal Plain, from which only 10 % of planted cotton seeds emerged after a crust had been formed.

Hutson (1971) reported on experiments in which the effect of crust strength of a Hutton Shorrocks (Rodhic Paleustalf) soil on the emergence of wheat seedlings was studied. Emergence occurred only when the modulus of rupture was below 40 kPa.

Emergence of bean seedlings decreased from 100 to 0% as the crust strength, measured by modulus of rupture, increased from 15 to 40 kPa, whereas the emergence of grain sorghum seedlings decreased only when the crust strength exceeded 13 kPa, but ceased above 170 kPa (Richards, 1953; Parker & Taylor, 1965)

Arndt (1965b) stated that the natural cracking pattern of crusts and the size of the seedling are often more important factors in seedling emergence than any other particular aspect of crust strength. A large variety of seedling emergence mechanisms exist. He presented 6 examples of crusts, based on cracking characteristics and seedling size (Figure 1.2) which represent the following cases:

In Figure 1.2a there is an adequate cracking for seedlings. The cracks are sufficiently frequent and wide to permit free emergence of most of the seedlings either directly or by reasonable detours.

In Figure 1.2b cracking is adequate for coarse seedlings.

In Figure 1.2c there is an inadequate cracking for fine seedlings. This causes delayed and partial emergence by detouring.

In Figure 1.2d, representing a common and serious impedance class, cracking is inadequate for free emergence of the seedlings.

In Figure 1.2e there is an absence of cracks. Fine seedlings are shown germinating under the crust. The seedlings cannot emerge unless the seeding density is high enough for the combined effort to produce shear failure of the crust.

In Figure 1.2f coarse seedlings are impeded by a seal without cracks, a situation common in sandy soils and heavier soils when wet. The crust is held rigid over the seedling by its wide extent. When coarse seedlings exert enough force on the lower surface of the crust, the rupture has the form of an inverted cone.

In general there are two types of deformation produced by emerging seedlings, tensile failure and shear failure. Tensile failure is the rupturing of soil crusts by emerging shoots. An example is shown in Figure 1.2b. Rupturing may involve either general or local tensile failure. When a failure is general, by definition, it extents to a soil boundary. In local failure the tension cracks do not extend to the boundary but are accommodated by compression of the soil.

Besides failing under tension, soils also fail under shearing stress imposed by plant organs. An example of general shear failure caused by seedling emergence is given in Figure 1.2f. The soil fails along the surface forming an inverted cone having its apex at the top of the seedling.

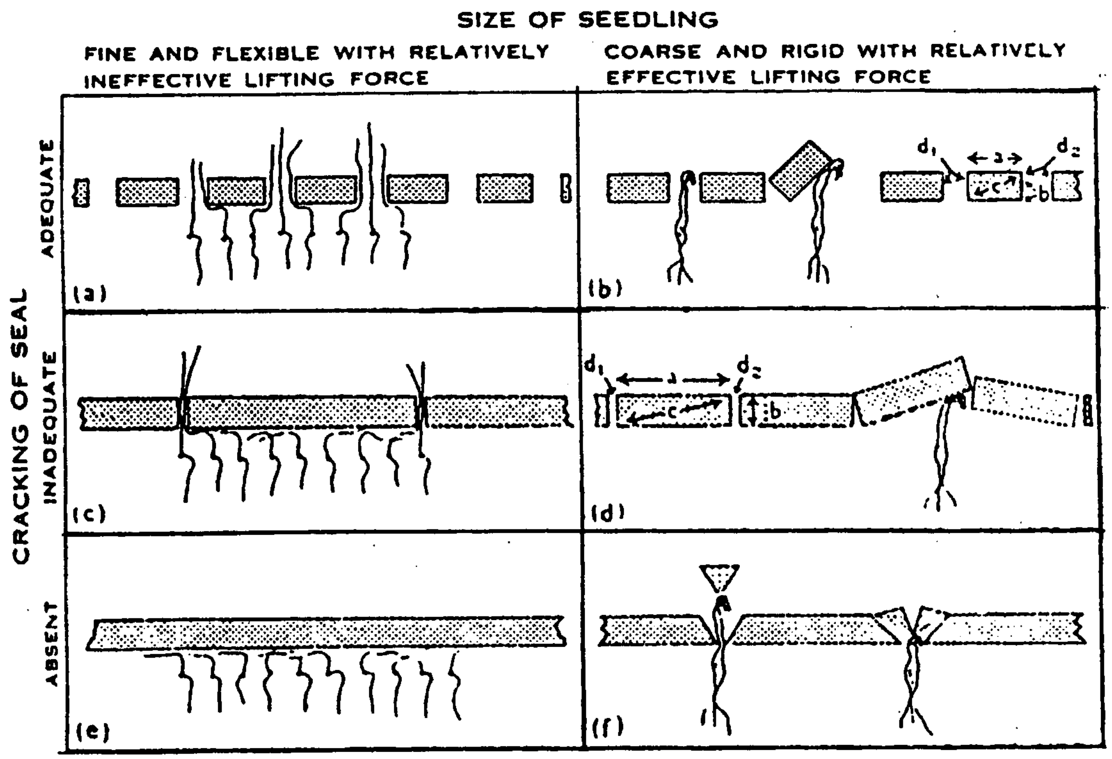

Figure 1.2: The main combination of seedling size and crust cracking characteristics used in identification of impedance mechanisms (Arndt, 1965b).

In the situation shown in Figure 1.2b the width (a) of the plate and thickness (b) are such that the diagonal dimension (c) is greater than the combined widths of the plate and the adjoining cracks d_1 and d_2, that is $(a^2 + b^2)^{1/2} > a + d_1 + d_2$. In order to emerge, the seedling has to overcome the gravitational force exerted by the plate, any cohesion that exists between the plate and the soil below, and sliding frictional resistance between the soil plate and the underlying soil. Whenever $(a^2 + b^2)^{1/2}$ equals or just exceed $a + d_1 + d_2$ jamming with neighboring plates will occur and a compression stress acting in a horizontal direction through these plates will be produced.

The crust strength value, inhibiting seedling emergence, also depends upon soil wetness. Other factors that influence the ability of seeds to emerge are crop species, variety, initial seed mass, soil temperature and depth of planting. Deep planting of seeds reduced the chances of seedling emergence because by the time the coleoptile reaches the soil crust, the crust had harden (Hanks & Thorp, 1957; Hadas & Stebbe, 1977).

All these factors add to the difficulty of establishing critical crust strengths, because of the variation encountered due to the nature of plant, soil temperature, soil wetness, and water content of the crust at the time of emergence.

1.2 The influence of texture on soil crusting

Soil texture seems to be an important soil variable influencing surface crusting (Mannering, 1967). Crusting can occur on soils of almost any texture except coarse sands with an extremely low silt and clay content (Lutz, 1952). Crusts form more readily on sandy loams than on clay loams, but soils with high silt contents favor crusting (Tackett & Pearson, 1965).

Bradford & Huang (1992) illustrated the influence of silt and clay content on crust formation. They exposed five soils (< 20 mm aggregates) to simulated rainfall at an intensity of 64 mm/h for 1 hour. The results showed that for a sand content less than

10%, increasing silt content from 51 to 84 % while decreasing clay from 45 to 85% resulted in a more than 6 times strength increase (Table 1.1).

Table 1.1: Indices of crust formation on five soils resulting from simulated rainstorm of 64mm/h for 1 h (Bradford & Huang, 1992)

Soil texture	Sand (0.05–2.00mm)	Silt (0.002-0.05mm)	Clay (< 0.002mm)	Strength (kPa)
Silt clay	4	51	45	12.5
Silt clay	4	53	43	19.5
Silt loam	4	73	23	32.2
Silt loam	6	80	14	74.2
Silt loam	8	84	8	84.0

Kemper & Noonan (1970) found that soils with sand contents between 50 and 80 % are prone to crusting. Arshad & Mermut (1988) described several types of crusts that form on high silt, low organic matter soils of Northwestern Alberta, Canada, indicating that the clay and sand amount may be less important than the silt content in determining crusting susceptibility.

Soils in Israel with approximately 20 % clay tended to have the most crusting problems. Soils with < 20 % clay had too little clay to disperse and clog pores, while soils with > 20% clay had stable structure. (Ben-Hur, Shainberg, Bakker & Keren, 1985).

Mannering (1967) studied the susceptibility of 58 soils, ranging in texture from sand to clay, to surface crusting. The degree of surface crusting was evaluated by measuring the soil strength with a penetrometer, or modulus of rupture, and hydraulic conductivity for soils subjected to 30 minutes of simulated rainfall. The results showed that very few soils were resistant to surface crusting.

In a laboratory experiment on the size distribution of eroded material from four Iowa soils under simulated rainfall, Gabriel & Moldenhauer (1978) showed that the sand, silt and clay content of the crust differed significantly from that of the original soil. In general the silt and clay contents of the crust were higher than that of the original soil. This was similar to the observation of Lemos & Lutz (1957), who found that the amount of silt was higher in the crusts of five soils from Southeastern United states than in the original soils.

1.3 The effect of crop residues on surface crusting

The value of crop residue mulches for preventing soil crust formation was reported by Mehta & Prihar (1973). Protecting the soil surface with crop residue against the impact of raindrops can be expected to be a most effective method of avoiding surface crusting.

Crop residues that are left on the surface of a soil prevent the formation of a crust by dissipating the energy of raindrops before they strike the soil surface (Ekern, 1950). They break the direct contact between soil surface and atmosphere resulting in reduced evaporation and thus keeping the surface layer wet for a longer period. This also helps to keep the soil strength low and facilitates emergence (Chaudhry & Das, 1978). A mulch also increases the wet aggregate stability of soils thus, the aggregates are more resistant to breakdown and subsequent sealing.

Mehta & Prihar (1973) found that a straw mulch on the entire surface of a soil is beneficial in reducing the crust formation and increasing seedling emergence. Also, infiltration remains high enough for rainfall to be completely absorbed when the degree of soil cover approaches 100%. Although the major contribution of a mulch in increasing infiltration appears to be the elimination of the destructive effect of raindrop impact on the soil surface, mulching has been found to also increase infiltration by retaining excess surface water longer in contact with the soil surface. (Adams, 1966). In some of the studies cited (Lopes, Cogo & Levien, 1987; Roth, Meyer, Frede & Derpsch, 1988; Carvalho, Cogo & Levien, 1990), 6 to 8 t ha^{-1} of wheat straw was required to attain 90 – 100 % soil cover.

Ranganatha & Satyanarayana (1979) have shown that the placement of straw mulches on seedrows resulted in the highest seedling emergence in a sandy loam soil. Application of straw mulch on seedrows reduced the evaporation rate and thereby kept the soil moist for a longer period resulting in faster and better emergence. The straw mulch prevented the dispersion of the soil particles by dissipating the energy of the rain and thereby preventing crust formation.

Bennett *et al.* (1964) reported that on average only 10% of cotton seedlings emerged through a conventional seedbed, whereas 72% of seedlings emerged when rows were covered with straw mulches. Chaudhry & Das (1980) used a wheat straw mulch applied at a rate of 5 ton/ha to investigate the seedling emergence of summer legumes through a simulated soil crust. This treatment was compared to other treatments such as the application of farmyard manure and gypsum and four methods of planting (flat bed, furrow, ridge and dibbling). The results of the study showed that the mean (average of four crops) emergence count under a straw mulch (67.4%) was significantly higher than that of all other treatments. In this experiment the water content and crust strength of the soil under different treatments were also measured. The water content in the mulch treatment was 5 to 6 times higher than that of other treatments and the soil strength was about 3 to 4.5 times less. From the results it could be concluded that poor emergence of seedlings through surface crusts may be greatly alleviated by maintaining higher water contents and lower crust strengths with straw mulching.

1.4. Research objectives

Quantitative information for alleviating the adverse effects of crusting is limited. The aims of this research are to investigate the effect of crop residue cover and texture on the degree of surface crusting, using the percentage of seedling emergence, penetrometer resistance, and lifting force as indicators of crusting. Specific objectives are to:

1) Determine the influence of texture on the susceptibility of five soils for crusting;

2) Obtain relationships between the percentage emergence of wheat, sorghum, sunflower and soybeans and crust strength and;

3) Define experimentally the optimum level of crop residue cover that can be used to minimize the effects of surface crusting on different soils.

CHAPTER 2

MATERIALS AND METHODS

2.1 Soils

Topsoil (0-200mm) was gathered from five South African (Bloemfontein) soils. According to South African Soil Classification Working Group (1991) the Form and Families of the soils are Hutton Ventersdorp, Bainsvlei Amalia, Bloemdal Vrede, Valsrivier Wepener, and Valsrivier Aliwal. During collection the soils were coded as shown in Table 2.1. Subsamples of these soils were used to determine the particle size distribution, organic carbon content, exchangeable cations, cation exchange capacity and modulus of rupture (Table 2.1).

2.1.1 Particle size distribution

The distribution of particle size was determined with the pipette method using a 50g sample of the soil passed through a 2mm sieve. The separation of sand, silt, and clay fractions was done according to the procedures described by The Non-Affiliated Soil Analysis Work Committee (1990).

Soil particles were separated in the following classes: < 0.002mm (clay), 0.002 – 0.02 mm (fine silt), 0.02 – 0.05 mm (coarse silt), 0.05 – 2.00 mm (sand) and < 0.05 mm (silt plus clay).

2.1.2 Organic carbon content

The organic carbon content (0C, %) was determined using the wet oxidation method (Walkley-Black method). The subsamples were grounded manually and passed through a

0.35mm sieve. The determinations were made in triplicate and performed as described by The Non-Affiliated Soil Analysis Work Committee (1990). The organic carbon concentrations were expressed as percentage of oven dry soil mass.

2.1.3 Cation exchange capacity and exchangeable cations

Methods for determining cations exchange capacity (CEC, cmol(+).kg^{-1}) and exchangeable bases involve displacement of the ions from soil and measuring the concentrations in the leachate. The displacement of ions was done using ammonium acetate as described by The Non-Affiliated Soil Analysis Work Committee, (1990).

Table 2.1: Some physical and chemical properties of the soils used in the experiments

Soil form and family	Soil code	Particle size distribution (%)				Exchangeable cations (cmol(+) kg^{-1})				CEC (cmol(+) kg^{-1}	O C (%)
		Sand	Silt	clay	S+C	Ca	K	Mg	Na		
Hutton Ventersdorp	A	93.5	2.28	4.4	6.68	1.0	0.3	0.3	0.1	3.5	0.24
Bainsvlei Amalia	B	88.2	3.54	8	11.54	1.5	0.3	0.6	0.1	4.2	0.12
Bloemdal Vrede	C	67.6	16.86	14.8	31.66	4.5	0.8	1.1	0.1	7.7	0.95
Valsrivier Wepener	D	67.6	14	18.4	32.4	4.9	0.9	0.5	0.1	9.1	0.48
Valsrivier Aliwal	F	46.4	24.76	28.9	53.7	17.9	1.6	2.1	0.4	21.8	1.33

2.2 Experimental procedures

2.2.1 Seedling emergence experiments

Four pot experiments, one on each crop type, with 5 soils, 6 residue rate treatments and 5 replicates were conducted successively in the greenhouse. A full-randomised design was used. The wheat residue rate treatments were:

T1= 0 ton/ha	T4 = 3 ton/ha
T2 = 1 ton/ha	T5 = 4 ton/ha
T3 = 2 ton/ha	T6 = 6 ton/ha

Air dried soil from each soil type was passed through 6mm sieve and placed in pots, 200 mm in diameter and 300 mm deep in two stages. During the first stage the soil was packed to 60 mm from the top of the pot and was watered to the field capacity one day before sowing. The following equations were used to calculate the amount of water that should be added to the pots:

$\theta_b = 0.0037 * (S+C) + 0,139$ (Bennie, Strydom & Vrey, 1998) (2.1)

$\theta_b * d * A = mm^3$ of water to be applied to the soil (2.2)

Where θ_b is the volumetric water content (v/v), (S+C) is silt plus clay content of the soil in percentage, d is the depth of the soil (120mm), and A the area of the pot ($31400mm^2$). The amount of water added per pot, depending on the soil type, is shown in Table 2.2.

During the second stage the wetted soil surfaces of the pots were redisturbed before placing the seeds on top of the wet soil. Five seeds were placed in each pot before more soil was added to cover seeds with 30 mm of soil.

The seeds were seeded in a circle 40 mm away from the edge of the pot, and 50 mm apart. Immediately after adding the last layer of soil, wheat residue of 0; 3.14; 6.28; 9.42; 12.56 and 18.84 g/pot, equivalent to 0; 1; 2; 3; 4 and 6 ton/ha respectively, were applied to the pots. Thereafter, the pots were subjected to simulated rainfall with distilled water at 120 mm/h intensity. The duration of the application differed in he experiments according to the soil type. The duration of the application for each soil type was taken as the time required to reach ponding for the bare pots (Table 2.2).

The rainfall simulator used in the experiments was described by Claassens & Van der Watt (1993).

The temperatures in the greenhouse were kept at 35° C (day) and 15°C (night) for 72 hours in order to allow for sufficient drying of the surface to promote the formation of crusts. Thereafter the day temperature was reduced to 24°C for the rest of the experiment. The number of emerged seedlings per pot was recorded each morning.

Table 2.2: Duration of exposure to simulated rainfall for each soil in terms of time to ponding and the volume of water applied to the bottom layer of soil in each pot

Soil form and family	Time to ponding (min)	Water added (cm^3)
Hutton Ventersdorp	20	617
Bainsvlei Amalia	20	678
Bloemdal Vrede	4	954
Valsrivier Wepener	3.75	976
Valsrivier Aliwal	4.3	1272

Seedlings of four crops were used in this study: Wheat (*Triticum aestivum* L.), Soybean (*Glicine max*. L.), grain sorghum (*Sorghum bicolor* L.) and sunflower (*Helianthus annus* L.). The depth of sowing was kept constant at 30 mm for all crops.

2.2.2 Penetration resistance and emergence force experiments

Two sets of pots were prepared in the same way as for seedling emergence experiments with the same number of treatments but only replicated twice. The pots were used for recording of penetration resistance of the crusts and for determination of emergence forces required to break the crusts. The penetrometer readings were taken in the first group of pots without seeds at the time required for 100 % emergence (Section 2.5). In the second group of pots 5 beads, each tied to a 200 mm long fishing line, were buried at a depth of 30 mm in the same configuration as the seeds to simulate the seeds. At the end of the experiment these beads were pulled from the soil to measure the force required to rupture the crust (Section 2.6).

2.3 Estimation of the percentage residue cover

Lang & Mallet (1982) used a sighting frame to estimate the percentage residue cover. In this study the same principle was used. Since the diameter of the pots was 200 mm, a ruler of 200 mm length was placed in the pot. The one-centimeter intervals on the ruler were used as sighting points. When the sighting point intersected with a piece of residue it was counted as a strike. Equation 2.3 was used to calculate the residue cover per pot.

$$RC = [(\text{total number of strikes}) / 20] * 100 \quad (2.3)$$

Where RC is residue cover in percentage.

The mean percentage wheat residue cover calculated with Equation 2.3, is shown in Table 2.3.

Table 2.3. Mean percentage residue cover of the pots at the different wheat residue rates

Residue rate (ton/ha)	Number of strikes	Residue cover (%)
0	0	0
1	5	25
2	9.5	42.5
3	14	70
4	18	90
6	20	100

2.4 Modulus of rupture

Modulus of rupture measurements of crust strength were replicated five times for each soil type. The method of Richard (1953), which measures the modulus of rupture of oven-dried moulded soil briquettes, was used. The briquet moulds were made of brass strips with inside dimensions of 35 mm by 70 mm by 0.952 mm high.

A beam balance was used to apply and measure the load to break the briquettes. A jet of water was directed towards a deflector on the end of the beam that intercepted the water and directed it into a vessel, where it accumulated as long as the briquet remained unbroken. The vertical drop of the end of the balance that occurred when the briquet broke was used to automatically stop the accumulation of water in the vessel. As the vessel drops, the jet of water was no longer intercepted. One valve was used on the line that supplied the jet of water to regulate the flow rate and another to open and shut-off the water jet. The water that accumulated in the vessel was weighed and used to calculate the modulus of rupture of the briquet.

2.5 Penetration resistance

Twelve pots from each soil, without seeds, were used to determine the penetrometer resistance of the soil crust. The pots were filled with soil and prepared similarly to the seedling emergence experimental pots (Section 2.2.1). After the application of the simulated rainfall the pots were allowed to dry for ten days. A 3 mm base diameter penetrometer probe with 60° cone-shaped point was pushed mechanically into the soil at a constant rate of 10 mm/h (Bennie & Botha, 1988). Five readings per pot were taken at a depth of 2 mm. The pressure readings were taken in a circle 40 mm away from the wall of the pot and 50 mm apart. The average of five readings per pot was expressed in MPa.

After taking the penetrometer pressure readings, soil samples were collected at a depth of 2 mm, weighed and dried in ventilated oven at 105°C for 24 hours, to determine the gravimetric water content of the crusts at the time of reading.

2.6 Emergence force

The procedure used by Bennett *et al.* (1964) to measure the force required to rupture soil crusts, was used in this study with minor adaptations. In each experiment 12 pots, without seeds, were also prepared similarly to the seedling experimental procedures (Section 2.2.1). A very thin nylon fish line of 200 mm length was tied at one end to a plastic bead with a 5 mm diameter and the other end was left protruding over the surface. The beads were used to simulate seeds with a 5 mm diameter. The beads were buried in the same configuration and manner as the seeds. After 10 days of drying, the protruding end of the nylon fish line was tied to a hook and the force required to pull the beads from the soil was recorded and the readings were converted to gram forces (gf).

2.7 Statistical analysis

Analysis of variance was used to compare the differences between soil water content, penetration resistance, emergence forces, and percentage seedling emergence among treatments. Turkey-Kramer tests were used to compare the means of measured parameters for the different treatments.

CHAPTER 3

INDICATORS OF THE MECHANICAL STRENGTH OF SURFACE CRUSTS

3.1 Introduction

The mechanical resistance of surface crusts is affected by many factors such as rainfall intensity and duration, rate of drying, soil texture, organic matter content, type of clay, degree of cracking, and water content (Hanks & Thorp, 1957; Taylor, 1962). A harder and less permeable soil crust develops under the following conditions (Hillel, 1960; Hanks, 1960):

- Low organic matter and high silt contents;
- Small aggregates at the surface prior to wetting;
- High water content at the surface due to slow drying.

In general crust strengths are higher in soils with high silt and fine sand contents, and which are structural unstable when wet (Ghildyal & Tripathi, 1987).

According to Ramley & Bradford (1989), the apparent degree of crusting depends upon the index or parameter chosen to characterize crust strength. Several researchers like Morrison, Prunty & Giles (1985) and Bradford, Ramley, Ferris & Santini (1986) have used surface strength to characterize the degree of crust formation. Commonly used methods are the modulus of rupture of dry soils and penetrometer resistance of moist soils.

Modulus of rupture measures the breaking strength of a dry crust, which is the maximum stress that a dry soil crust can withstand without breaking. It was found that the modulus of rupture is strongly dependent on the water content of the soil crust or briquettes used for measurement (Richards, 1953; Ghildyal & Tripathi, 1987).

Penetrometer measurements taken at a constant penetration rate was also used to determine the crust strength. A penetrometer is a device of which the probe is forced into the soil to measure the resistance that the soil offers to vertical penetration. The resistance of a soil to the penetration of a probe is an index of soil strength under the conditions of measurement.

Crust strength can also be measured from below the crust, simulating emerging seedlings (Morton & Buchele, 1960; Arndt, 1965a, 1965b; Gerard, 1980). Morton & Buchele (1960) developed a penetrometer to measure the upward mechanical force exerted by a seedling through a soil crust. Using various sizes of probes to represent different seed diameters, they found that the emergence energy increased directly with seed diameter, degree of crusting, depth of planting and decreasing water content.

Arndt (1965b) designed an instrument that records the upward force measured by a mechanical probe that is buried in the soil prior to the formation of a surface crust. This probe penetrates the crust as it is forced upward. The measured impedance in a Tippera sandy clay was 2165 gf. Holder & Brown (1974) used the same principle to evaluate the simulated seedling emergence through rainfall induced soil crusts of a loam soil and found a maximum impedance of 2226 gf.

Pulling a buried fishing line, that is attached to an object simulating a seed, to the surface of the soil was also used to make crust strength measurements (Bennett *et al.*, 1964; Ghildyal & Tripathi, 1987). Bennett *et al.* (1964) related cotton seedling emergence to the force required to pull a seed attached to a fishing line through a crust of a sandy loam soil. They found a progressive decrease in cotton seedling emergence as the force measured increased from 449 to 1377 gf.

Lateral anchorage of seedlings is extremely important for shoots to exert its potentially available thrust. When a zone of low strength is present immediately below a high strength layer, a seedling shoot will tend to bend and grow horizontally rather than vertically (Chambers, 1962). However the effect of various levels of lateral anchorage on seedling thrust has not been determined.

The force exerted by seedlings plays an important role in its ability to rupture crusts and to emerge to a satisfactory stand (Gerard, 1980). Despite the importance of seedling emergence very little research has been conducted to better understand seedling characteristics. Williams (1956, 1963) used probit analyses and reported that the maximum emergence force exerted by forage legumes in a fine sandy loam soil ranged from 50 to 60gf. Gerard (1980) evaluated the emergence force of cotton seedlings through crusts of a Miles fine sandy loam soil, using a transducer, and reported that cotton seedlings exerted maximum forces of 600 and 400 gf at 27 and 32° C respectively at a water content of 15%. The techniques that were used in this study to access the crust strength of the soils with different textures were described in Sections 2.4 to 2.6.

The objectives with this chapter will be i) to compare various techniques for measuring crust strength; ii) to relate the measured crust strength to some soil properties and iii) to quantify the effect of different levels of residue cover on measured crust strength.

3.2 Results and discussion

3.2.1 Modulus of rupture as an index of soil crust strength

The moduli of rupture of the soils used in the pot experiments are presented in Table 3.1.

Table 3.1: Moduli of rupture of the soils

Soil code	Soil type and texture	Modulus of Rupture (kPa)	Silt (%)	Clay (%)	Silt plus clay (%)	Organic matter (%)
A	Hutton Ventersdorp (Sand)	1.447	2.28	4.4	6.68	0.41
B	Bainsvlei Amalia (Sand)	2.785	3.54	8.0	11.5	0.21
C	Bloemdal Vrede (Sandy loam)	6.175	16.86	14.8	30.9	1.63
D	Valsrivier Wepener (Sandy loam)	9. 862	14.0	18.4	32.4	0.83
F	Valsrivier Aliwal (Loam)	3. 708	24.76	28.9	53.7	2.29

The soils can be ranked in terms of modulus of rupture as A < B < F < C < D. The two soil properties that best explain crust strength are silt and organic matter contents (Tackett & Pearson, 1965; Taylor, Roberson & Parker, 1966b; Nuttall, 1982; Arshad & Mermut, 1988; Bradford & Huang, 1992). From the data presented in Table 3.1 it is clear that with the exception of soil F, which has a higher organic matter content, the modulus of rupture of the other soils increased with an increase in silt and silt plus clay contents. Soils C and D have almost similar silt contents but because of a higher organic matter content soil C had a lower modulus of rupture. Soil F with the highest silt content had the third highest

modulus of rupture because of a relatively high organic matter content. Soil F, because of its high clay content, showed vertic characteristics like cracking and a stable microstructure. This soil also contains some free lime that ensures good clay flocculation, which contributes towards decreasing the modulus of rupture.

3.2.2 Penetration resistance of the surface crusts

The mean penetrometer resistance of the crusts at the different levels of residue cover, 10 days after sowing, is given in Table 3.2 for all the soils. This Table also shows the water contents of the crusts at the time when the penetrometer readings were taken. The penetration resistance and water content relationships for each individual soil are presented in Appendix 3.1. The relationships between penetrometer resistance and residue rate or residue cover are illustrated in Figures 3.1 and 3.2 respectively, for the different soils.

In general, the highest crust penetrometer resistance occurred at 0 % residue cover for all the soils. Soil F, with vertic properties, formed cracks on the surface with drying. This resulted in low PR-values because the cracking ruptured and destroyed the crust. When the crust penetration resistance (PR, MPa) of the soils without residue cover are compared, soils C and D had the highest PR-values in order of 2 MPa. This value is in the range of 1.7 MPa and 2.6 MPa reported by Gerard (1980) for a sand loam soil with a similar texture as soils C and D. The difference between soils C and D is not significant.

Soils A and B had crust PR-values in the order of 1.2 MPa for the bare pots which is lower than the maximum penetration resistance value of 1.42 MPa for a sandy soil (20% silt plus clay), reported by Rapp, Shainberg & Banin (1999). Considering the amounts of silt plus clay of soils A and B which is less than 12%, the PR-values for these soils is acceptable. The difference between soils A and B is also not significant.

Table 3.2: Mean penetration resistance (PR) and emergence force (EF) with corresponding gravimetric water content (WC) of the soil crusts for the different soils and treatment

	Soils									
	A		B		C		D		F	
Residue rate (Ton/ha)	PR (MPa)	WC (%)	PR (MPa)	WC (%)	PR (MPa)	WC (%)	PR (MPa)	WC (%)	PR (MPa)	WC (%)
0	1.198	1.029	1.227	1.360	2.037	2.787	2.078	2.508	0.616	6.217
1	0.929	1.117	1.035	1.483	1.597	2.813	1.742	3.504	0.666	7.077
2	0.851	1.105	0.738	1.817	1.592	2.659	1.674	3.737	0.699	7.440
3	0.668	1.421	0.681	1.865	1.309	2.703	1.369	4.117	0.681	7.744
4	0.564	1.870	0.621	1.630	0.950	3.594	1.185	4.441	0.642	9.719
6	0.515	1.958	0.316	2.693	0.665	4.388	0.958	4.508	0.738	9.783
LSD (0.05)	0.11 .		0.21		0.35		0.35		0.21	
	EF (gf)	WC (%)	EF (gf)	WC (%)	EF (gf)	WC (%)	EF (gf)	WC (%)	EF (gf)	WC (%)
0	682.0	1.89	549.0	1.88	1340	3.10	2036	3.91	989.5	6.36
1	521.0	1.97	511.0	2.14	767.0	3.44	1932	4.08	700.5	6.47
2	492.5	1.92	426.5	2.45	942.0	3.60	1733	4.20	559.0	6.71
3	459.5	2.35	379.0	2.73	639.0	3.61	1430	4.27	521.0	7.13
4	402.5	3.12	308.0	2.89	568.0	3.74	1193	4.33	407.0	8.03
6.	293.5	5.9	217.5	3.52	492.0	4.43	923.0	4.54	274.5	8.36
LSD (0.05	122.1	3.16	62.42	2.99	331.3	11.84	626.3	2.00	102.4	2.32

The crust PR-values of the soils without residue cover can be ranked as C = D > A = B. The most obvious reason for the higher crust PR of soils C and D can be ascribed to the higher silt plus clay contents which increased the consistency of the soil crusts.

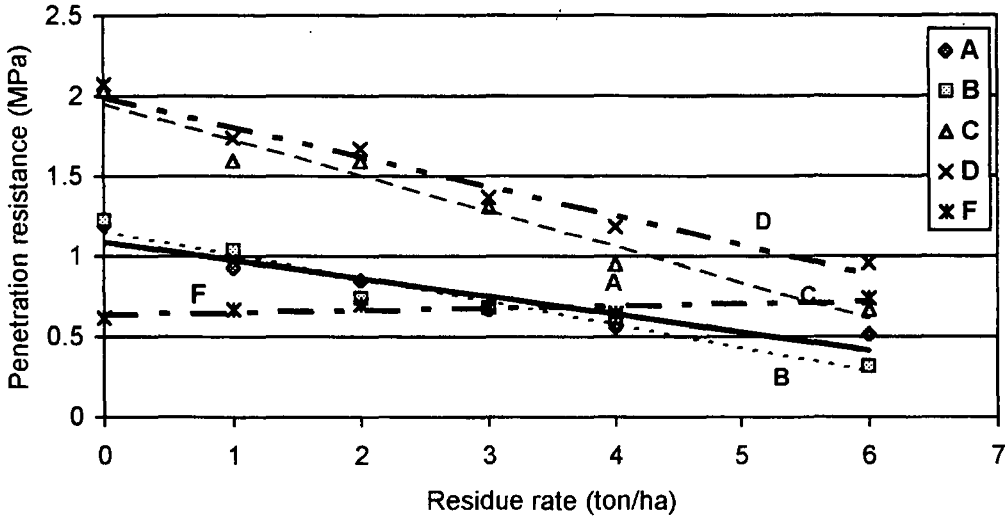

Figure 3.1: Relationship between penetration resistance and residue rate.

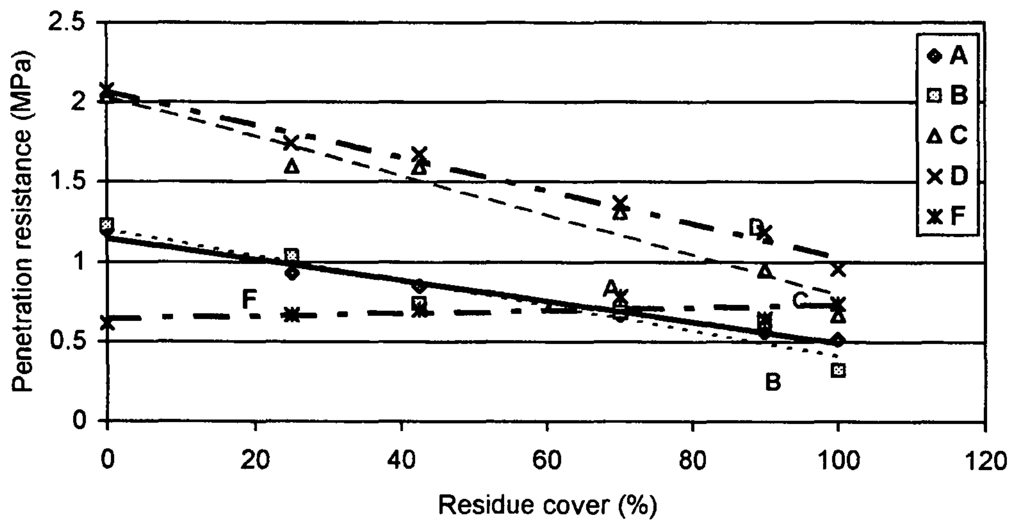

Figure 3.2: Relationship between penetration resistance and residue cover.

One of the methods used to mitigate the adverse effects of soil crusts is maintaining a surface mulch of crop residues (Ranganatha & Satyanarayana, 1979; Chaudhry & Das, 1980). Regression lines were fitted to the penetration resistance versus residue cover data and a linear relationship described the data best (Equation 3.1).

$$PR = a + b*RC \qquad (R^2 > 0.91) \qquad (3.1)$$

Where PR is the penetration resistance of the soil crusts (MPa), a is the intercept, b is the slope of the lines, and RC the percentage of residue cover. The values of coefficients a and b for the different soils are presented in Table 3.3.

Table 3.3: Regression coefficients for the relationship between PR and RC for the different soils

Soil Code	A	B	R^2
A	1.145	-0.0066	0.98
B	1.201	-0.0079	0.91
C	2.035	-0.0124	0.95
D	2.069	-0.0104	0.98
F	0.6432	0.0009	0.30

The presence of crop residue mulches resulted in a progressive decrease in crust strength as the mulch cover increased from 0 to 100 % or 1 to 6 ton/ha, except for soil F where the penetration resistance remained constant. A possible explanation is that crop residue on the surface of the soil reduces crusting by dissipating the energy of raindrops. Where a crust is formed the crop residue mulch also reduces the evaporation and keeps the soil moist for a longer period, resulting in lower crust strength (Mehta & Prihar, 1973). From the data presented in Table 3.2 it can be observed that for all the soils the water content at the surface increased with increasing percentage residue cover.

To illustrate the relative effectiveness of the different degrees of residue cover on reducing the crust penetration resistance of the soils, the penetration resistance residue factor (PRRF) was used as an indicator. This factor was calculated as:

$$PRRFj = PR_{ij} / PR_{oj} \quad (3.2)$$

Where PRRFj is the penetration resistance residue factor for soil j, PR_{ij} is the penetration resistance of the crust at residue cover i on soil j and PR_{oj} is the penetration resistance of the crust of soil j without residue cover.

From the results illustrated in Figure 3.3 it is clear that a linear decline in the PRRF with increasing residue cover were obtained for all the soils with the exception of the cracking soil F where residue cover had no effects (Equation 3.3).

$$PRRF = 1 - c*RC \quad (3.3)$$

Where PRRF is the penetration residue factor, c the slope of the lines, and RC the percentage of residue cover.

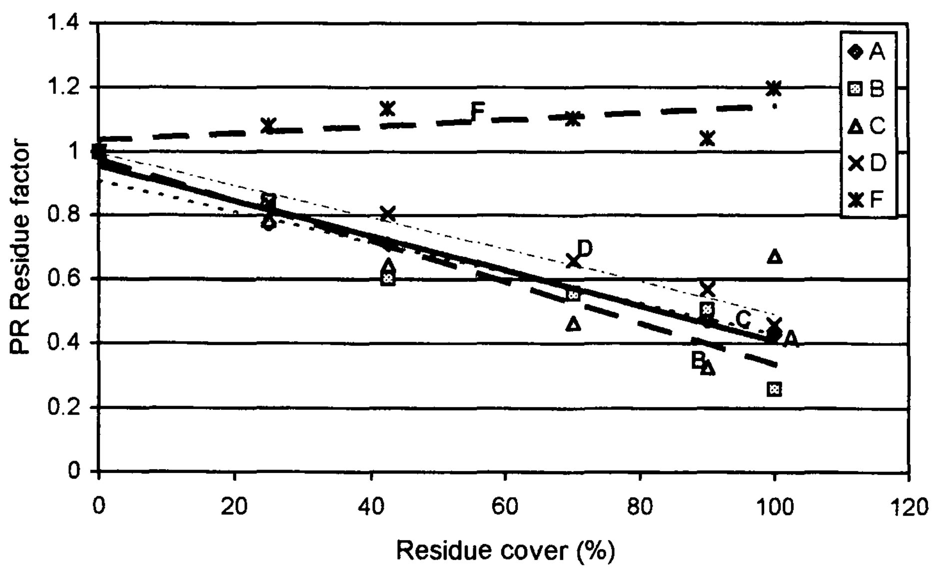

Figure 3.3: Penetration resistance residue factor as a function of residue cover

The values of the slopes of the lines for different soils are presented in Table 3.4.

Table 3.4: Regression coefficient from relationship between PRRF and RC

Soil code	Intercept	Slope (c)	R^2
A	1	- 0.0060	0.96
B	1	- 0.0067	0.91
C	1	- 0.0061	0.95
D	1	- 0.0051	0.98
F	1	0.0015	0.27
A to D combined	1	- 0.0060	0.92

For the non-cracking soils A to D the small differences among the slopes of the lines indicate that the effectiveness of the residue mulch cover in reducing the magnitude of crusting was similar for all these soils. It is proposed that a constant slope of –0.006 can be used to calculate the PRRF from the percentage residue cover for non-cracking soils with less than 25 % clay. When the crust PR (PR_{oj}, MPa) for bare soil (j) with less than 25% clay content is known the PR_{ij} (MPa) at any residue cover (RC, %) can be calculated with Equation 3.4.

$$PR_{ij} = PR_{oj} * (1 - 0.006 * RC) \qquad (R^2 = 0.92) \qquad (3.4)$$

For soils with more than 25% clay, which cracks upon drying (soil F) mulching does not affect the crust strength as measured with a penetrometer.

3.2 3 Emergence forces required to fracture soil crusts

The mean emergence forces (gram force, gf), measured as the force required to pull a 5 mm diameter bead from the different soils, and corresponding water content, are presented in Table 3.2. The emergence forces for the different soils are also presented as functions of crop residue cover and residue rate in Figures 3.4 and 3.5 respectively

The highest emergence forces were measured at 0% residue cover for all the soils and could be ranked in the order of D > C > F > A > B (Figures 3.4 and 3.5). Again a higher silt plus clay content of non-cracking soils appear to be the most obvious reason for the increase in emergence forces. Soil F with the highest clay content had, because of its vertic cracking properties, moderate emergence force values.

The reason why soil A, with a lower silt plus content and higher organic matter content, had higher emergence forces than soil B is difficult to explain, because the water contents of crusts were almost the same (1.89%).

The values of the emergence forces ranging from 549 to 2036 gf, measured in this study, are less than the 2165 gf for Tippera sandy clay and 2226 gf for Lufkin loam soil reported by Arndt (1965b), and Holder & Brown (1974) respectively, who used buried probes to simulate seedlings (Section 3.1). Values for the maximum actual emergence forces that can be exerted by seedlings, that are available in the literature (Williams, 1956, 1963; Jensen, Frelich & Gifford, 1972; Gerard, 1980; Rathore *et al.*, 1981), vary from 50 to 600 gf depending on the type of crop, water content of the soil crust, and soil type. It is known that the mechanism for soil rupture by seedlings differs from rigid objects. Seedlings usually require a lower emergence force.

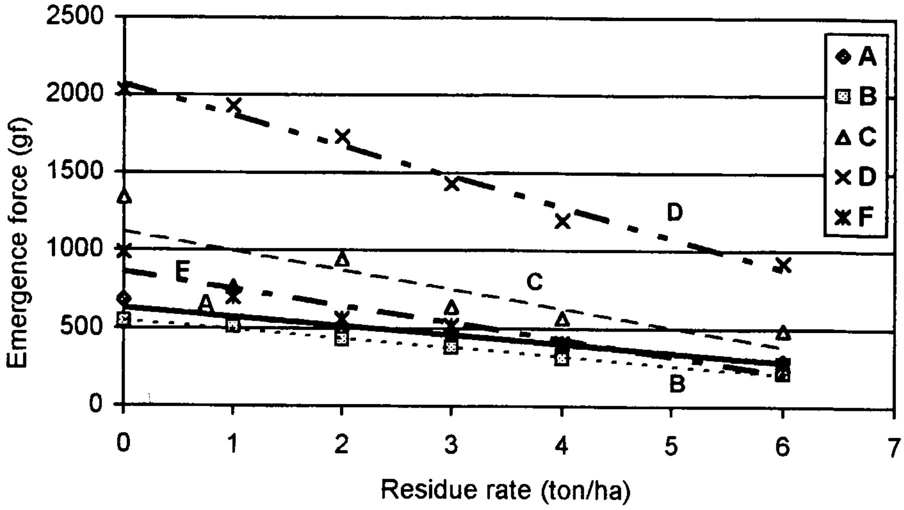

Figure 3.4: Emergence force as a function of crop residue rate.

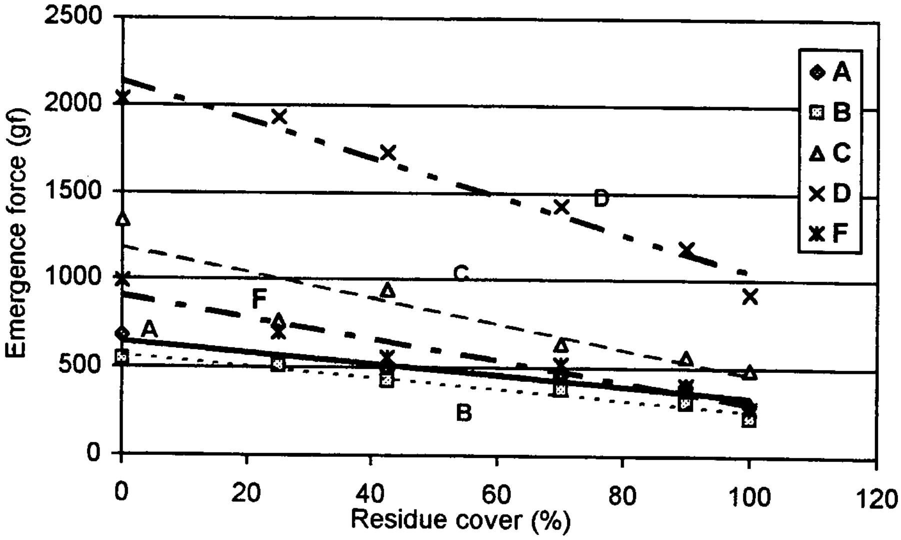

Figure 3.5: Emergence force as a function of crop residue cover.

The relationship between emergence forces and residue cover or residue rate indicate a negative linear relationship of the type:

$$EF = a + b * RC \qquad (3.5)$$

Where EF is the emergence force (gf), a and b are the intercept and slope of the lines respectively and RC the percentage residue cover. The values of the coefficients a and b are presented in Table 3.5.

Table 3.5: Values of the intercept and slopes of the regression lines between emergence force and residue cover for the different soils

Soil code	Intercept (a)	Slope (b)	R^2
A	648.0	-3.166	0.98
B	569.1	-3.125	0.95
C	1188.0	-7.266	0.82
D	2140.9	-10.99	0.96
F	911.7	-6.165	0.93

The negative linear relationship between emergence forces and residue cover indicate that the presence of crop residue resulted in a decrease of the force required to pull the beads from the soil, probably because the presence of crop residue on the surface of the soil kept the soil wetter and reduced crust formation.

The relative effectiveness of the different degrees of residue cover on reducing the load required to pull the buried beads out of the soil was compared by using an emergence force residue factor (EFRF) as an indicator, calculated as:

$$EFRF_j = EF_{ij} / EF_{oj} \qquad (3.6)$$

Where $EFRF_j$ is the emergence force residue factor for soil j, EF_{ij} is the emergence force of soil j at residue cover i, and EF_{oj} is the emergence force of the soil j without residue cover.

Linear relationships between the emergence force residue factor were obtained for the different soils (Figure 3.6). The intercepts and slopes of the lines are presented in Table 3.6.

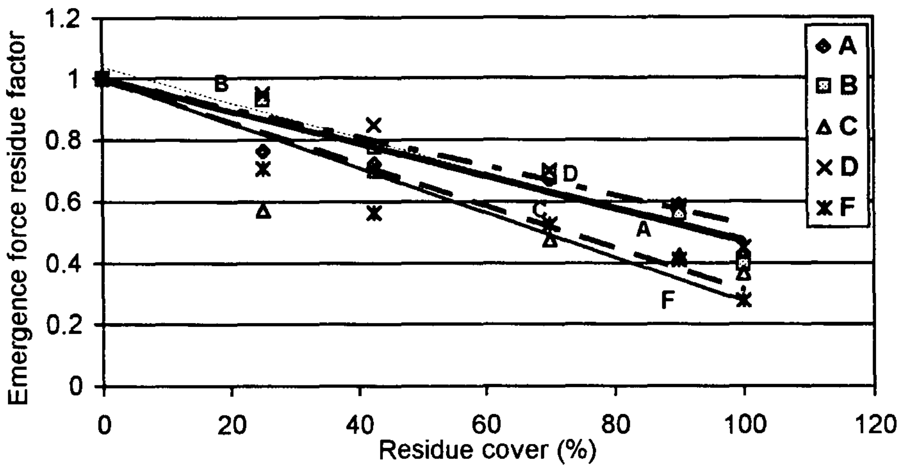

Figure 3.6: Emergence force residue factor as a function of residue cover.

Table 3.6: Coefficient of regression between emergence force residue factor and residue cover

Soil code	Intercept	Slope (d)	R^2
A	1	-0.0053	0.88
B	1	-0.0052	0.94
C	1	-0.0069	0.73
D	1	-0.0047	0.94
F	1	-0.0072	0.89
Mean	1	-0.006	0.80

The values of the slopes of soils A, B, and D are not significantly different. But these values are significantly different from soils C and F, which are steeper than the others. This means that a given percentage of residue cover will decrease the emergence forces more for soils C and F than for soils A, B and D. The mean slope of - 0,006 for all the soils is similar to the value found for the reduction in penetration resistance.

3.2.4 Selected soil properties and their relationship with crust strength

Soil crusts form from wetting of the soil surface followed by particle re-orientation during drying. This seems to cause certain changes in the properties of the surface layer, which may result in high strength of the surface crusts (Sharma & Agrawal, 1980).

Soil properties such as organic matter content, bulk density, exchangeable sodium percentage, structure and textural parameters were found to be highly related to crust strength (Tackett & Pearson, 1965; Mannering, 1967; Kemper & Noonan, 1970; Sharma & Agrawal, 1980; Nuttal, 1982; Ben-Hur *et al.*, 1985).

As discussed in Section 3.1 penetrometer resistance, modulus of rupture and emergence force are widely used to characterize crust strength. The effect of some soil properties such as silt, clay, silt plus clay, organic matter, and soil water content on crust strength will be the topic of the following discussion.

3.2.4.2 Modulus of rupture

Polynomial relationships between modulus of rupture and the silt, clay, silt plus clay and organic matter contents were observed (Figures 3.7 to 3.10). The coefficients of regression (R^2) of the equations in Figures 3.7 to 3.10, showed that clay content appears to give the best relationships with modulus of rupture. Further, the high R^2 - value with silt suggested that silt content makes a major contribution towards the modulus

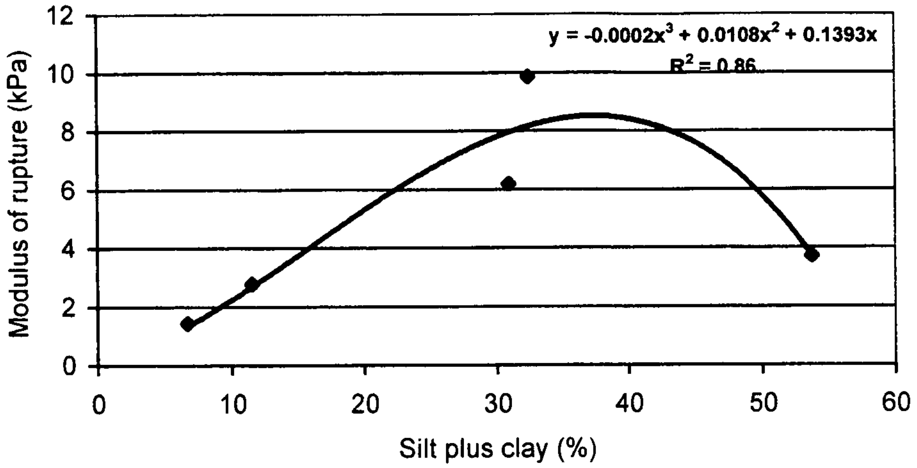

Figure 3.7: Relationship between modulus of rupture and silt plus clay content.

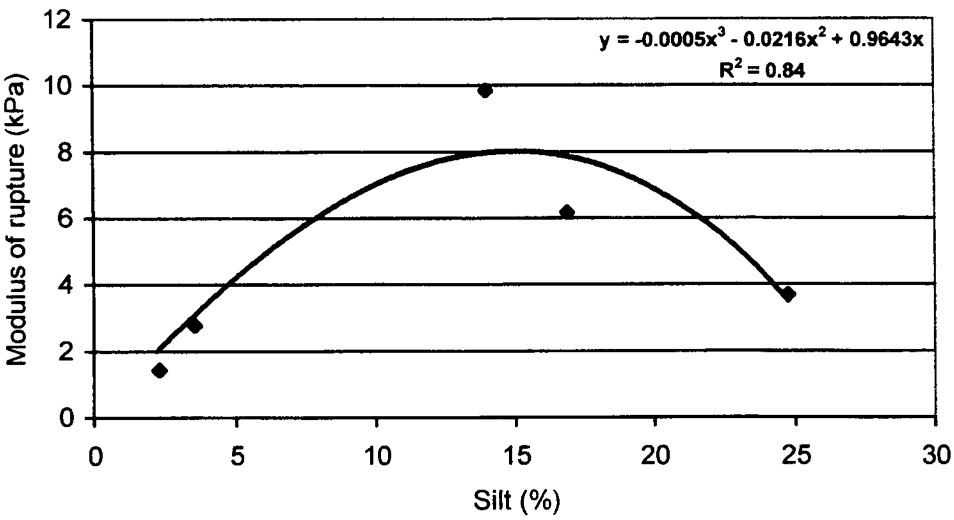

Figure 3.8: Relationship between modulus of rupture and silt content.

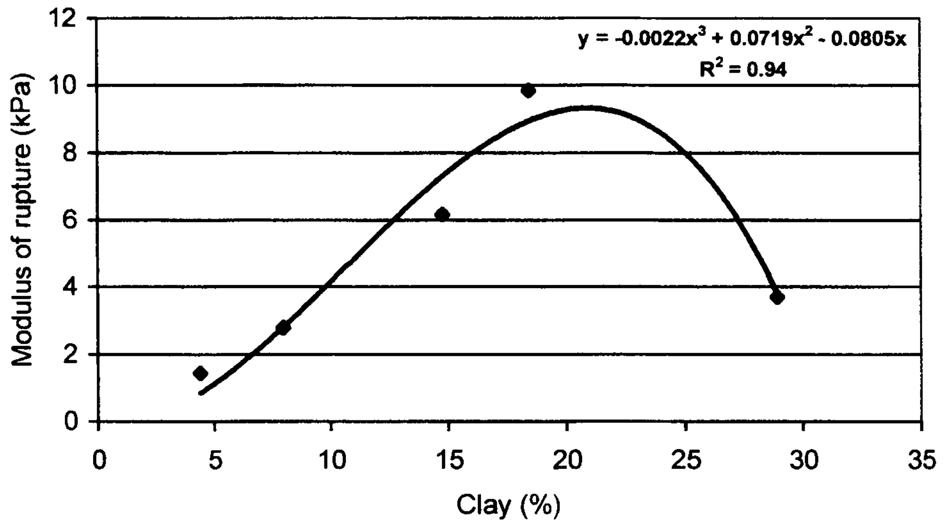

Figure 3.9: Relationship between modulus of rupture and clay content.

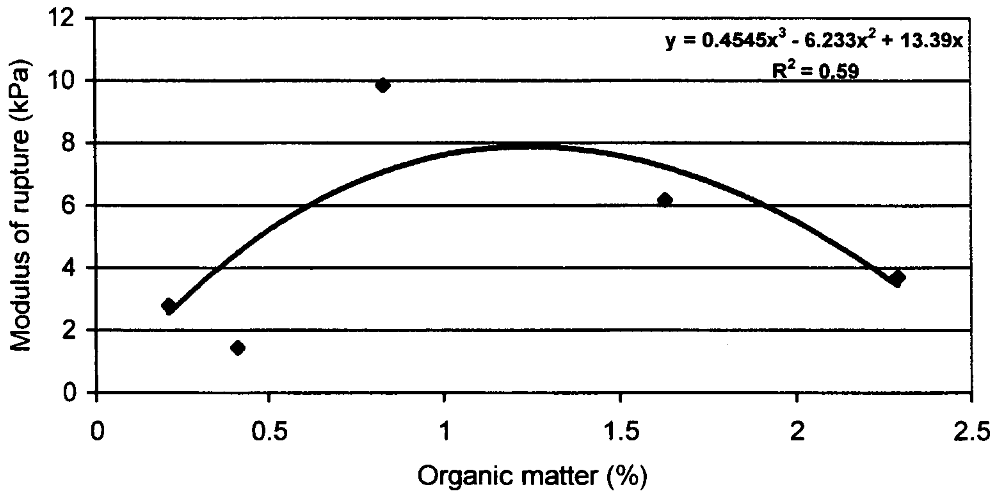

Figure 3.10: Relationship between modulus of rupture and organic matter content.

of rupture of a crust. The reason for the increase in modulus of rupture with increasing clay content (Figure 3.9) can be attributed to the corresponding increase in total surface area available for surface to surface attraction and cementation (Sharma & Agrawal, 1980). The correlation that was observed between modulus of rupture and organic matter content suggests that organic matter also played a role as a binding agent in structureless soils.

The polynomial relationship in Figures 3.7 to 3.10, especially the relationship between modulus of rupture and silt plus clay content (Figure 3.7) and clay content (Figure 3.9) can be explained as follows: For soils with less than 20 – 25% clay or 35 – 40% silt plus clay the modulus of rupture increases almost linearly with an increase in the fine particle content because it increases the consistency. Soils with more than 20 – 25% swelling clays or 30 – 40 % swelling clays plus silt, the clay content will be high enough for surface crusts to be fractured by cracking, resulting in a decline in crust strength or modulus of rupture.

3.2.4.3 Penetration resistance

The relationship between the penetration resistance of the soil crusts, in the pots without residue cover, and silt plus clay, silt, clay, and organic matter are shown in Figures 3.11 to 3.14. In general, there is an increase in penetration resistance with an increase in silt plus clay, silt, clay and organic matter contents to a certain point after which it declined. The R^2-values of the regression equations in Figures 3.11 to 3.14 show clearly that the silt plus clay, silt and clay contents respectively, correlated best with the penetrometer resistance of the crusts. The good relationships between the fine particle content and crust penetrometer resistance accentuate the importance of particle orientation upon wetting and drying as an important mechanism for crust formation on sandy soils (Gal, Arcan, Shainberg & Keren, 1984).

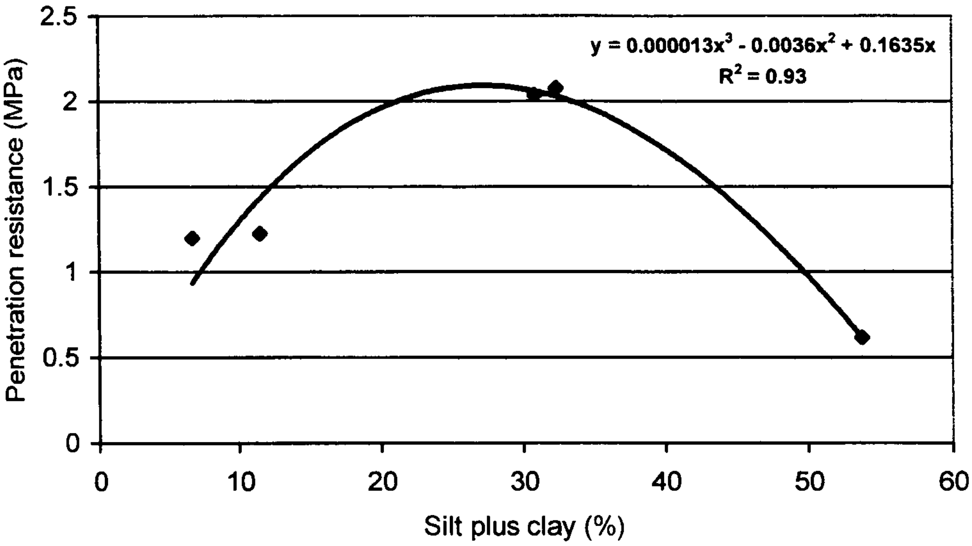

Figure 3.11: Penetration resistance as a function of silt plus clay content.

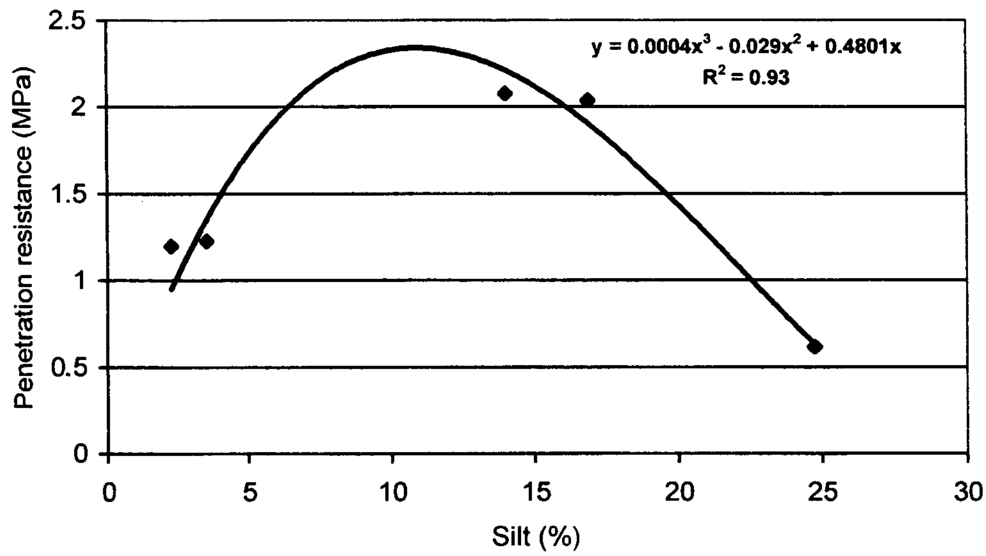

Figure 3.12: Penetration resistance as a function of silt content.

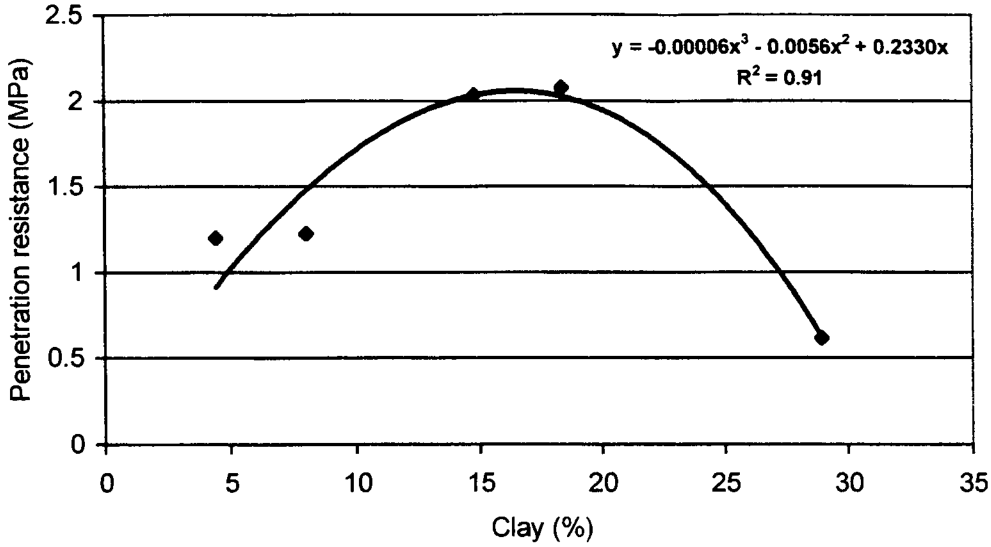

Figure 3.13: Penetration resistance as a function of clay content.

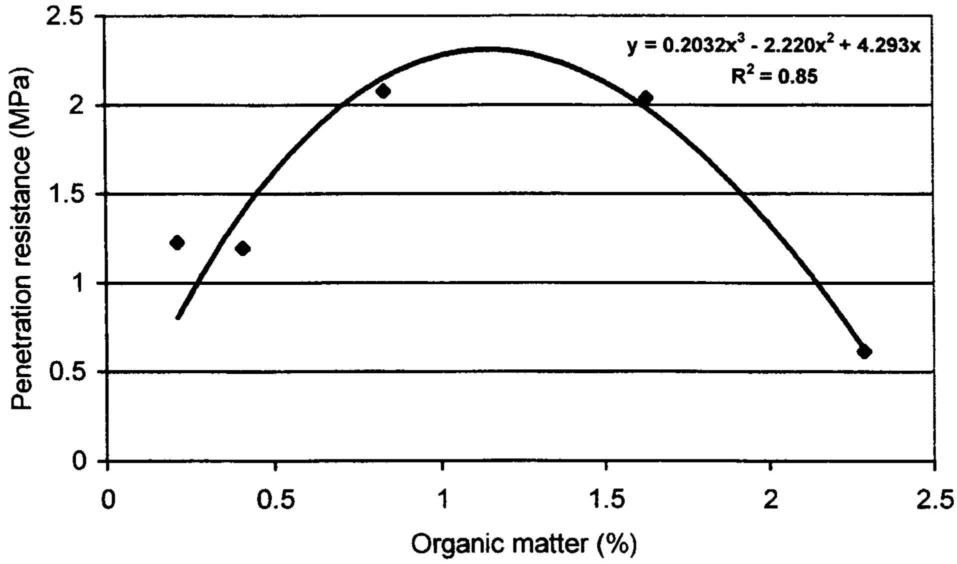

Figure 3.14: Penetration resistance as a function of organic matter content.

The explanation for the polynomial relationships is the same as for modulus of rupture, discussed in section 3.2.4.2. An increase in the silt and clay contents up to about 35% is responsible for an increase in consistency and crust penetration resistance. A further increase in the fine particle content, especially swelling clays, causes the crust to shrink and rupture upon drying with a corresponding decline in crust penetration resistance (Figures 3.11 to 3.13).

The polynomial relationship between crust penetration resistance and organic matter content (Figure 3.14) is probably merely a product of the good relationship between clay and organic matter contents of the soils (Table 3.1).

3.2.4.4 Emergence force

The relationships between the emergence force of the crusts formed in the pots without residue cover and silt plus clay, silt, clay and organic matter contents of the soils were also found to be of a third order polynomial (Figures 3.15 to 3.18). From the R^2 -values presented in Figures 3.15 to 3.18 the contribution of clay content towards emergence force crust strength seems to be the most important, followed by the silt and silt plus clay contents. The lowest R^2 - value was found for the relationship between organic matter content and the corresponding emergence forces (Figure 3.18).

Again the explanation for the polynomial character of the curves are the same as were discussed for the modulus of rupture (Section 3.2.4.2) and crust penetration resistance (Section 3.2.4.3). For all three indicators of crust strength, namely modulus of rupture, penetration resistance and emergence force, the maximum values, represented by the turning point of the curves, corresponded with the same fine particle contents. The corresponding values were 35 – 40 % silt plus clay and 20 – 25 % clay.

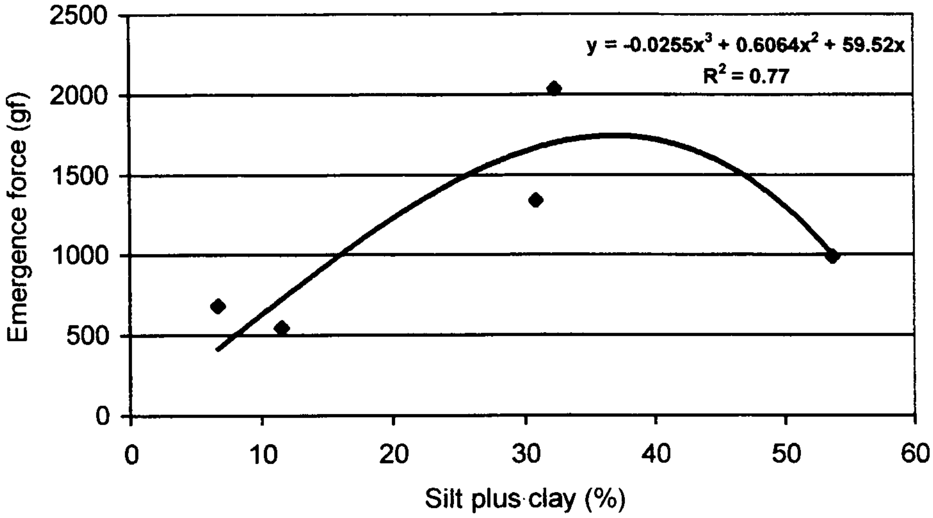

Figure 3.15: Emergence force and silt plus clay contents relationship.

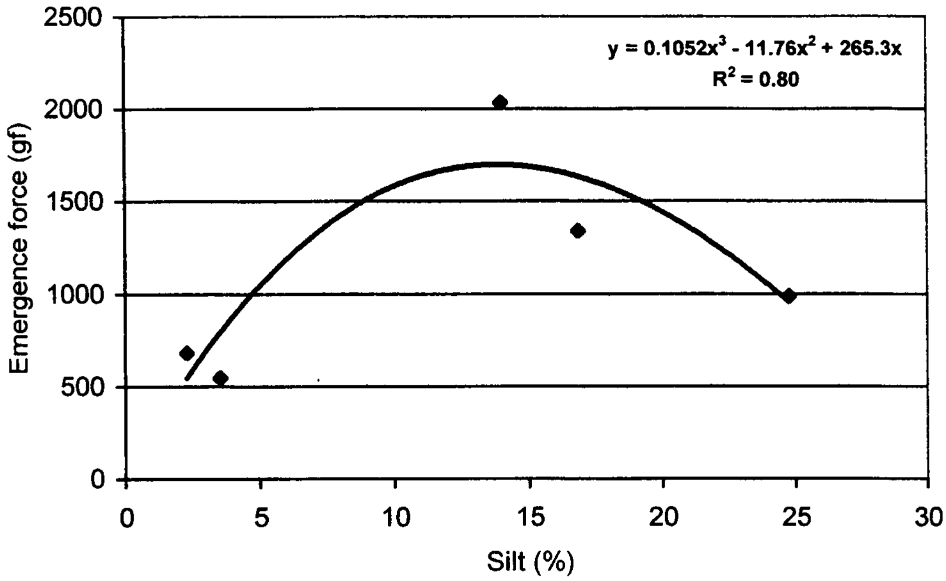

Figure 3.16: Emergence force and silt content relationship.

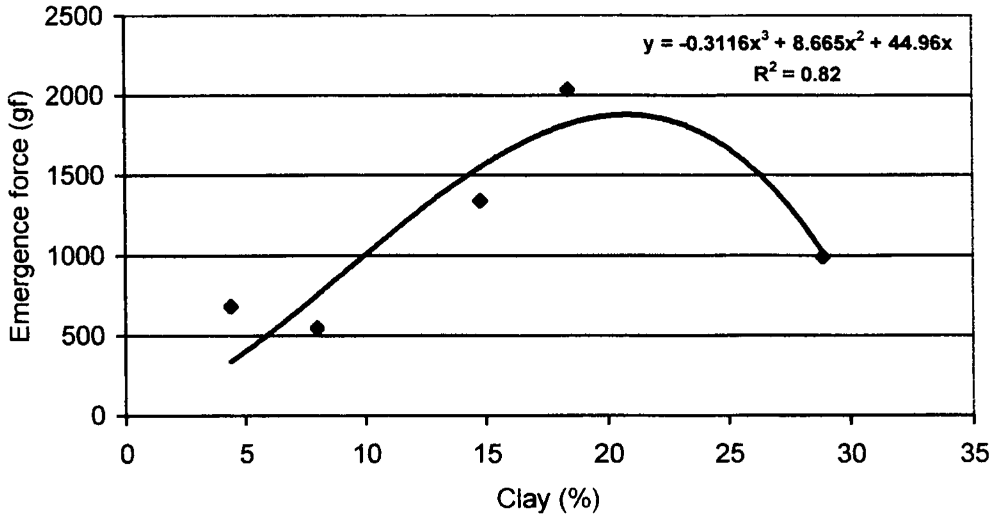

Figure 3.17: Emergence force and clay content relationship

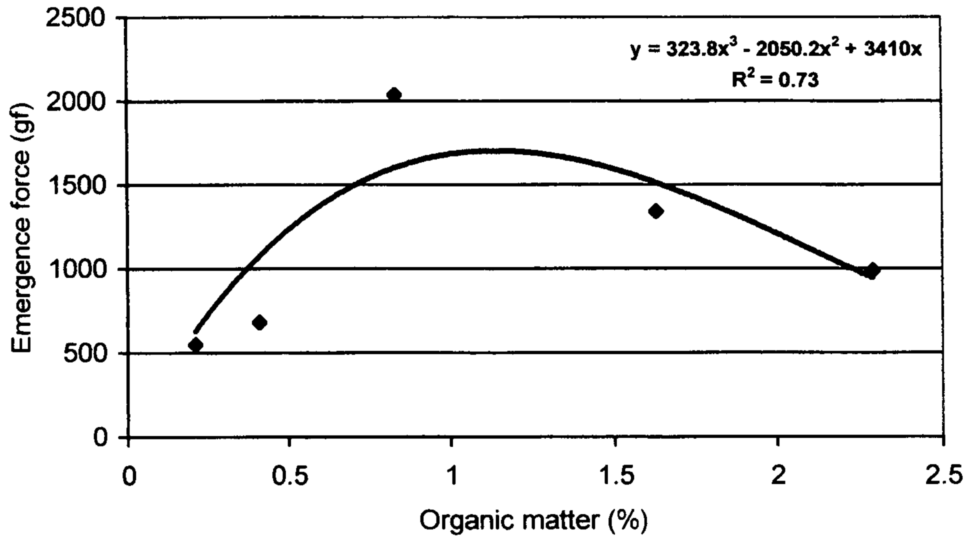

Figure 3.18: Emergence force and organic matter content relationship.

3.2.5 Estimation of crust strength from texture and percentage residue cover

The relationship between the penetration resistance, modulus of rupture and emergence force, the estimators of crust strength, and some soil properties were discussed in the previous sections. The results showed that silt, silt plus clay and clay contents of the soils were well correlated with the estimators of crust strength. It was also found that the crust strength of the different soils was highly influenced by the percentage of residue cover. Because of the good relationships between crust strength and silt (S, %), silt plus clay (S+C, %), clay (C, %) contents and percentage residue cover (RC, %), the crust strength as measured by penetration resistance and emergence force can be estimated as follows:

- Penetration resistance (PR, MPa):

$$PR = [0.000013 * (S+C)^3 - 0.0036 * (S+C)^2 + 0.1635 * (S+C)] * (1- 0.0060 * RC) \quad (3.7)$$

$$PR = [0.0004 * (S)^3 - 0.029 * (S)^2 + 0.4801 * (S)] * (1 - 0.0060 * RC) \quad (3.8)$$

$$PR = [-0.00006 * (C)^3 - 0.0056 * (C)^2 + 0.2330 * (C)] * (1 - 0.0060 * RC) \quad (3.9)$$

Where 1 – 0.0060 * RC = PRRF, the penetration resistance residue factor. The equations are only valid for soils with clay content less than 25%. For soils with more than 25% clay (soil F), the percentage residue cover had no effect on crust strength.

- Emergence force (EF, gf):

$$EF = [-0.0255 * (S+C)^3 + 0.6064 * (S+C)^2 + 59.52 * (S+C)] * [(1 - d) *RC] \quad (3.10)$$

$$EF = [0.1052 * (S)^3 - 11.76 * (S)^2 + 265.3 * (S)] * [(1 - d) *RC] \quad (3.11)$$

$$EF = [-0.3116 * (C)^3 + 8.665 * (C)^2 + 44.96 * (C)] * [(1 - d) *RC\} \quad (3.12)$$

Where (1-d) *RC = EFRF, the emergence force residue factor. The value of d is based on the soil type. According to the clay contents in Table 3.1 and the effectiveness of the crop residue cover (slopes) shown in Table 3.6, it is suggested that for soils with more than 15% clay content, a value of d = 0.0050 or 0.0070 for soils with more than 15% clay, can be used. An average value of d = 0.0060 will also give an acceptable prediction.

Modulus of rupture was not included in the estimation of crust strength from texture and percentage residue cover because the effect of residue cover was not directly related to the modulus of rupture.

The coefficients of determination ($R^2 > 0.75$) obtained for the relationships between silt, silt plus clay or clay and penetration resistance or emergence force (Figure 3.11 to 3.18), suggest that the estimation of crust strength from a single soil property may not always be accurate. It is recommended that the silt plus clay contents can be used to estimate crust strength (Equations 3.7 and 3.10).

3.3 Conclusions

The aim of this chapter was to evaluate crust strength by mean of various techniques as well as to determine the role of some soil properties in the formation of surface crust. From the results obtained the following can be concluded:

- Crust strength as measured by the three techniques, modulus of rupture, penetrometer resistance, and emergence force, showed the highest values for soils C and D. It can be concluded that any of the three methods can be used to access the strength of soil crusts. All the methods showed a certain consistency in terms of the soil properties that affected their magnitude. According to the results of this study, soils C and D can be classified as soils with a high susceptibility for crusting.

- Silt, silt plus clay, and clay contents of the soils were found to be the most important soil properties influencing crust strength. Silt plus clay contents of 35 to 40 % or clay contents of 20 to 25 % were found to correspond with the maximum crust strength. Above these values the crust strength decreased due to swelling and shrinking of the clays and consequent cracking of the soils. Below these threshold values, crust strength decreased because of the associated decline in soil consistency.

- Generally, the application of crop residue mulches on the soil surface reduced the crust strength considerably. The mulching effect, maintained higher water contents in the surface layer which helped to lower crust strength (Chaudhry & Das, 1980). Crust strength was found to decrease linearly with increasing levels of crop residue cover. Substantial decrease in crust strength can be achieved by maintaining more than 70 % soil cover by crop residue.

- Equations were derived that can be used to quantify the reduction in crust strength associated with a percentage residue cover. Regression equations that can be used to predict crust strength from texture and percentages residue cover were also proposed.

CHAPTER 4

EFFECT OF CRUST STRENGTH ON SEEDLING EMERGENCE

4.1. Introduction

In the absence of a crust, seedlings seem to emerge by weaving their way through voids and by displacing or deforming soil obstructions. When the apex is blocked, the stem tends to buckle in the direction of the least resistance, which is usually towards the surface, and emergence is achieved (Taylor, 1971). When the water content of the soil, and the size, shape and arrangement of voids vary, the method and ease of emergence appear to depend on the size of the seedlings. With an increase in the cross sectional area of the seedling stem, the flexibility of the stem decreases while the axial force that can be exerted increases. Therefore, as the diameter of the seedling stem increases, the greater lifting force tends to compensate for the loss of flexibility. These mechanisms allow most crops to emerge through a wide range of conditions in uncrusted soils (Arndt, 1965b).

Under crusted conditions, the resistance offered by the surface can cause buckling of the seedling which often proceeds to grow in a horizontal direction without emerging. Soil crusts impede the emergence of seedlings even when other factors like the availability of water, planting depth and oxygen supply are not limiting.

The emerging seedlings of cereals and grasses, with a diameter of about 1 mm or less, usually displace soil particles by compression and shear until the coleoptile tip is near the soil surface. When the force exerted by the coleoptile tip is sufficient to overcome the tensile strength of the soil crust, an inverted cone is ruptured out of the crust (Morton & Buchele, 1960).

Taylor *et al.* (1966b) found relatively small differences among grain sorghum, corn, wheat, barley and switchgrasses in the relationship between penetrometer resistance of the crust and seedling emergence. Their studies were conducted with seven soils ranging from a clay loam to loamy sand. A crust penetration resistance of 0.7 MPa, had little or no effect on emergence. Above that value emergence rapidly decreased, as the penetration resistance increased to about 1.5 MPa above which no emergence occurred.

Hanks & Thorp (1956, 1957), using the modulus of rupture as an indicator of crust strength, showed that the percentage emergence of wheat seedlings varied directly with the degree of drying. Hanks & Thorp (1957) showed that some wheat seedlings could emerge through crusts of 0.08 MPa strength, and that about 20% of grain sorghum seedlings could emerge through crusts with a modulus of rupture of 0.14 MPa.

Many dicotyledonous crops such as cotton, sunflower and beans must push their large cotyledons through soil crusts during emergence. The area of crust that a seedling needs to displace is much larger than the diameter of its stem, which exert the plant growth force. These seedlings emerge by rupturing the soil crust in the form of a dome or cone, which must be large enough for the cotyledons to pass through (Arndt, 1965a and b; Bowen, 1966).

Carnes (1934) found that cotton seedling emergence was reduced as the modulus of rupture increased. Hanks & Thorp (1957), using a similar technique, showed that 60% emergence of soybeans occurred through crusts with a modulus of rupture of 0.08 MPa.

In this chapter different rates of residue mulch will be used to obtain different crust strengths for five soils, differing in texture. The emergence percentage of wheat, sorghum, sunflower and soybean seedlings, as affected by crusting, will be measured.

4.2 Results and discussion

4.2.1 Effect of crust penetration resistance on seedling emergence

The ultimate seedling emergence percentages of soybeans, sunflower, sorghum and wheat at different rates of residue cover are given in Table 4.1. The relationships between the percentage seedling emergence and penetration resistance (PR) of all the soils combined are shown in Figure 4.1 for the different crops. The graphs for each separate soil are presented in Appendix 4.1. The emergence of sorghum will not be discussed here because crusts of low strength formed in the experiment with sorghum due to very slow drying caused by continuous cloudy conditions. This resulted in very high sorghum emergence percentages without any statistically significant differences among treatments.

In Figure 4.1 the decrease in seedling emergence with an increase in crust penetration resistance is confined as was also reported by Chaudhry & Das (1980); Rathore *et al.* (1983); Joshi (1987) and Rapp *et al.* (1999). For crust penetration resistances up to about 0.7 MPa, little or no decrease in seedling emergence occurred. The highest percentages seedling emergence ranged between 70 to 96% for soybean, 80 to 100 % for sunflower and 90 to 100 % for wheat. Above 0.7 MPa seedling emergence percentages decreased as the penetration resistance increased. No seedling emergence can be expected to occur above the calculated values of 2.46, 3.13 and 5.72 MPa for soybean, sunflower and wheat respectively (Equations 4.1 to 4.3).

The slopes in Equations 4.1 to 4.3 clearly indicate that wheat with the smallest slope was less affected by crust strength than sunflower and soybean for which the slopes were practically similar.

Table 4.1: Ultimate emergence percentages of soybean, sunflower, sorghum and wheat for different soils and residue rates

Crop	Soil	Residue rate (ton/ha)						LSD (0.05)
		0	1	2	3	4	6	
Soybean	A	24	36	44	52	52	80	48.86
	B	48	68	84	80	68	96	44.56
	C	20	24	40	56	64	72	43.41
	D	0	24	64	60	60	76	50.71
	F	64	68	84	84	84	72	35.32
	LSD (0.05)	55.75						
Sunflower	A	36	60	64	76	88	88	50.96
	B	32	32	68	80	80	92	50.96
	C	40	56	56	68	96	96	48.60
	D	12	52	68	64	96	84	47.87
	F	92	100	96	100	100	100	11.28
	LSD (0.05)	55.55						
Sorghum	A	76	88	88	88	88	84	Ns
	B	76	80	80	92	92	76	Ns
	C	76	88	92	88	84	88	Ns
	D	80	76	80	72	84	88	Ns
	F	80	84	80	84	84	84	Ns
	LSD (0.05)	Not significant (Ns)						
Wheat	A	72	84	88	100	96	96	26.22
	B	56	72	84	88	96	100	45.69
	C	76	92	100	92	100	92	34.22
	D	40	64	88	92	96	92	51.21
	F	92	88	92	96	96	96	22.28
	LSD (0.05)	46.75						

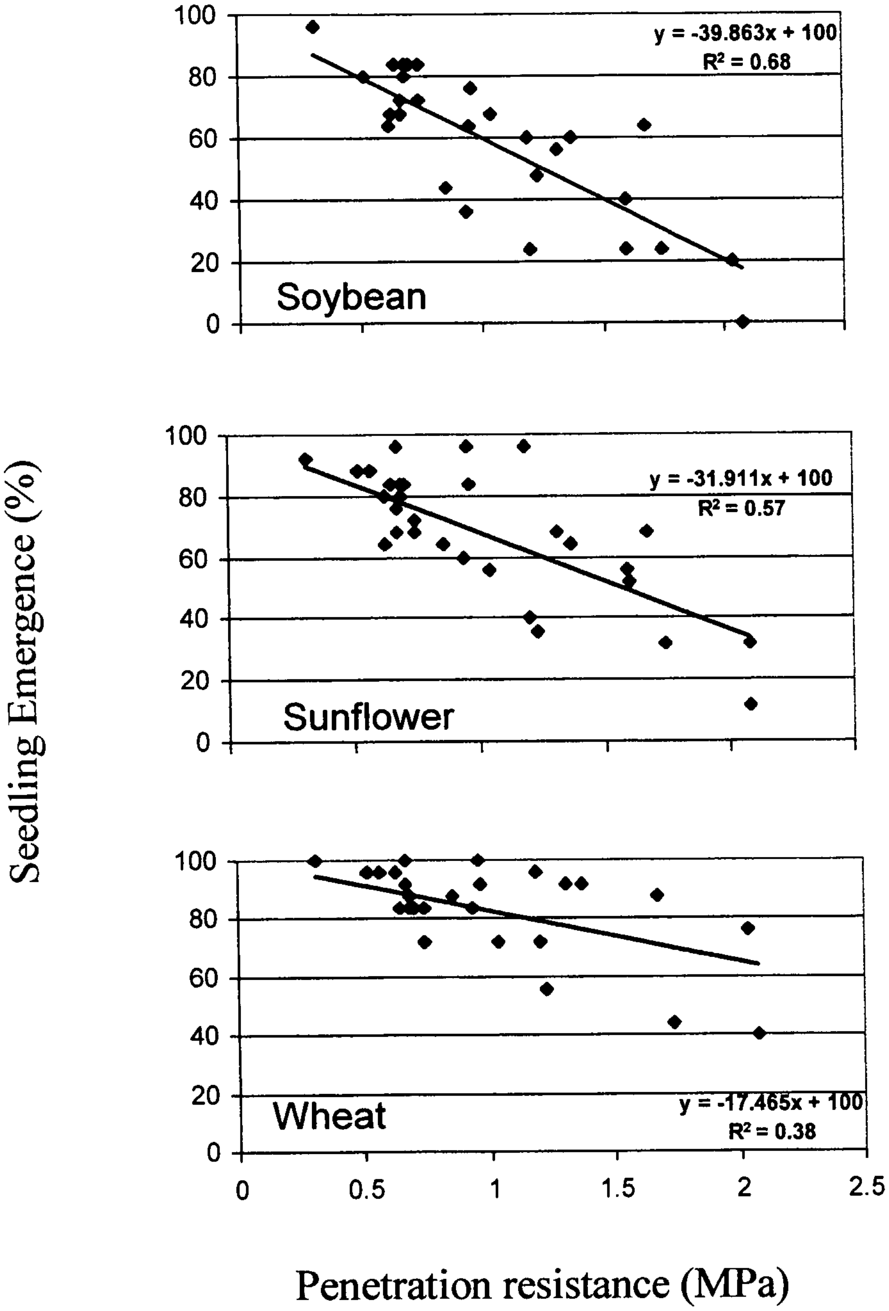

Figure 4.1: Relationships between percentage seedling emergence and crust penetration resistance for different crops for the combined data of all the soils.

$$WEM = -17.47 * (PR) + 100 \qquad R^2 = 0.38 \qquad (4.1)$$

$$SFEM = -31.91 * (PR) + 100 \qquad R^2 = 0.57 \qquad (4.2)$$

$$SBEM = -39.86 * (PR) + 100 \qquad R^2 = 0.68 \qquad (4.3)$$

Where WEM = Percentage wheat emergence; SFEM = percentage sunflower emergence and SBEM = percentage soybean emergence.

The coefficients of determination for Equations 4.1 to 4.3 ($R^2 < 0.70$) are low suggesting that other factors than crust strength also might have contributed to seedling emergence (Section 3.2.1).

4.2.2 Effect of emergence forces on seedling emergence

Emergence forces (EF, gf) were measured using a buried bead tied to a fish line and the force required to pull it from the crusted soils was measured (Section 2.6). The relationships between the combined emergence forces of the soils and percentage seedling emergence for the different crops are presented in Figure 4.2. The graph for each individual soil and crop is presented in Appendix 4.2. From Figure 4.2 it can be seen that the relationship between emergence force and percentage seedling emergence is linear and negative, i.e. there is a decrease in seedling emergence as crust strength increased from 250 to more than 2000 gf. Bennett *et al.* (1964) reported similar findings. The final seedling emergence at a crust strength of about 500 gf ranged between 60 to 100%. Low values of less than 20% seedling emergence were observed at crust strengths above 2000 gf (Figure 4.2).

Wheat seedlings appear to be less affected by crust strength while soybean seedlings are the most affected. The slopes of the regression lines relating seedling emergence percentage to emergence force are –0.0189, -0.0369 and –0.0459 for wheat, sunflower

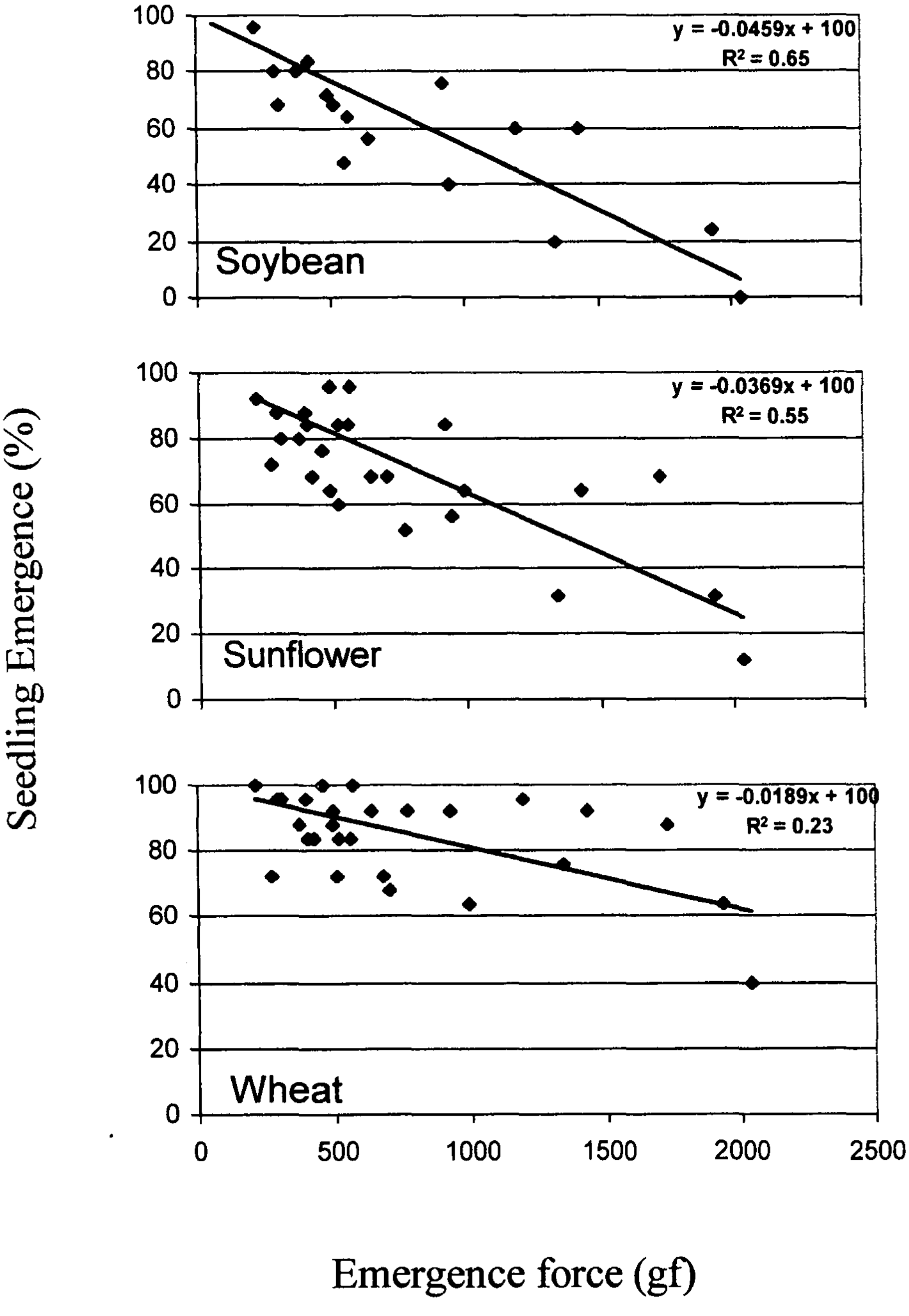

Figure 4.2: Percentage seedling emergence as a function of emergence force for different crops for all the soils combined.

and soybean respectively (Equations 4.4 to 4.6). The slopes of the lines are indications of the influence of emergence force crust strength on seedling emergence.

$$WEM = -0.0189 * (EF) + 100 \qquad R^2 = 0.23 \qquad (4.4)$$

$$SFEM = -0.0369 * (EF) + 100 \qquad R^2 = 0.55 \qquad (4.5)$$

$$SBEM = -0.0459 * (EF) + 100 \qquad R^2 = 0.65 \qquad (4.6)$$

The coefficients of determination ($R^2 < 0.65$) for Equations 4.4 to 4.6 are low suggesting that some other factors might also have been affecting seedling emergence (Section 4.2.1). The maximum force that the seedling must exert in order to emerge is a dynamic expression of continually changing environmental growth conditions (Gerard, 1980).

4.2.3 Effect of residue cover on seedling emergence

Crop residue mulch was spread on the surface of the pots at different rates before the application of simulated rainfall (Section 2.2). The achieved mean percentage soil cover per pot was 0, 25, 42.5, 70, 90 and 100%. Figure 4.3 represents the relationship between seedling emergence percentage of the different crops and residue cover (RC, %) for all the soils combined. The relationships between seedling emergence percentage of the different crops and percentage residue cover for each individual soil are represented in Appendix 4.3. From Figure 4.3 it is clear that the percentage seedling emergence increased with increasing residue mulch cover. This could be expected because of the good relationship between crust penetration resistance, emergence force and water content (Section 3.2). A crop residue mulch at the soil surface helps to protect the soil against the impact of raindrops causing crust formation and also, through reduced

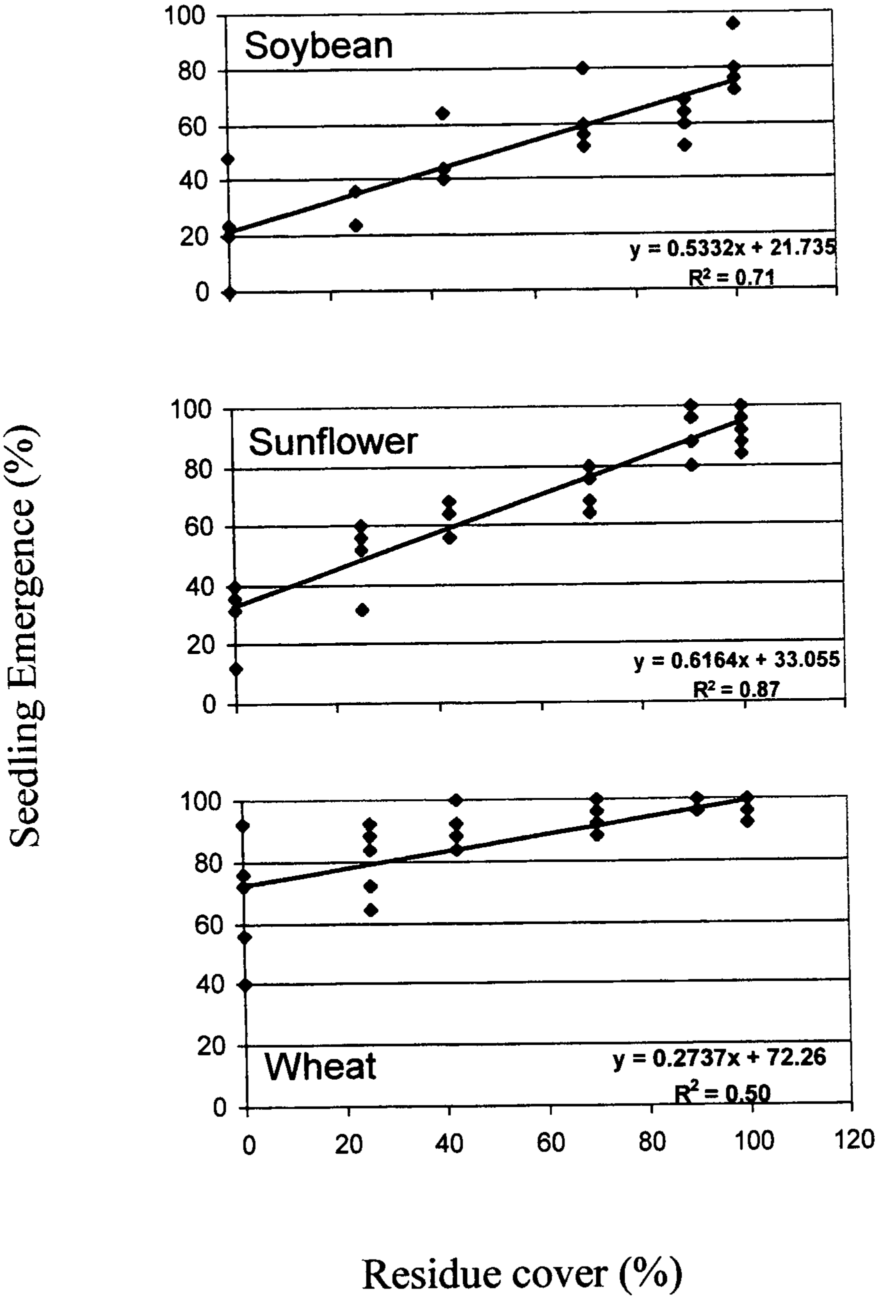

Figure 4.3: Relationship between the percentage seedling emergence of different crops and residue cover for all the soils combined.

evaporation keeps the soil crust wetter resulting in a low crust strength (Ranganatha & Satyanarayana, 1979; Awadhwal & Thierstein, 1985).

$$WEM = -0.2737 * (RC) + 72.26 \qquad R^2 = 0.50 \qquad (4.7)$$

$$SFEM = -0.6164 * (RC) + 33.06 \qquad R^2 = 0.87 \qquad (4.8)$$

$$SBEM = -0.5332 * (RC) + 21.74 \qquad R^2 = 0.71 \qquad (4.9)$$

4.2.4 Comparison between crops

The differences among crop species to emerge under bare crusted conditions are illustrated in Figure 4.3 and Equations 4.7 to 4.9. Wheat had the highest emergence of 72% and soybeans the lowest with 22%. The benefit of a crop residue mulch on seedling emergence will therefore be larger on larger seed dicotyledons.

From the results obtained in Sections 4.2.1 to 4.2.3 it is clear that wheat had a higher emergence percentage compared to sunflower and soybean. The difference between soybean and sunflower was very small and not significant. In general the emergence of wheat was higher than the emergence of sunflower and soybean under all treatments. Sivaprasad & Sarma (1987) explained the difference between wheat and sunflower or soybean by comparing the emergence of monocotyledon crops with that of dicotyledon crops and showed that dicotyledon crops emerged from the soil by breaking the impeding soil crust, while the monocotyledon crops emerged without noticeable disturbance of the crust. The dicotyledon crops (e.g. soybean and sunflower) with epigeal germination need to push two large cotyledons through the soil crust in order to emerge. Thus a large area of the crust must be ruptured to free the cotyledons and, therefore, a large total force must be exerted (Fapohunda, 1986), whereas the monocotyledon crops (e.g wheat) with hypogeal germination exert a thrust concentrated on a point load and displace the soil by shear or compression. On the other hand, the monocotyledons has the bullet coleoptiles which force its way to the soil surface, where it opens to expose the plumule (Taylor, 1971).

The differences in the percentage emergence of sunflower and soybean are mainly a function of their ability to emerge through the crust formed in the pots with no residue cover. The relative beneficial effect of residue cover on seedling emergence was the same for these two crops as can be seen in Figure 4.3. It is evident from Figure 4.3 and Equations 4.7 and 4.8 that the slopes of the linear equations, which are indicators of the effect of residue cover on the percentage seedling emergence, are practically similar.

It was observed in the experiments that when the growing hypocotyl of soybean and sunflower strikes the crust, it tried to deviate from its upward path in order to circumvent minor obstructions and followed the path of least resistance. When it failed to overcome the mechanical restraint imposed on it by the overlying crust it remained buried under the heavy crust (Plate 1). In some cases seedlings managed to emerge through cracks that were large enough to accommodate them. These cracks were occasionally formed along the seeded row as a result of internal stresses in the crust on drying (Plate 2, left side). This happened often in Soils C and D. In Soil F the cracks resulted from shrinking of the clay and thus the emergence of all seedlings was much easier in this soil. In some cases, individual or joint efforts were made by seedlings to break the overlying crust. The cracked and detached crust blocks were so hard and heavy that the seedlings remained captured under the crust. Rathore *et al.* (1983) studied the effect of crust impedance to soybean emergence and reported similar findings.

In order to investigate what happened to the seedlings that did not emerge at the end of the experiment, the upper layer of soil was removed. The seeds were found germinated but they could not emerge due to the effect of the high crust strength (Plate 3).

Plate 1: Sunflower seedlings that germinated and remained buried under soil crust, after the crust was removed.

Plate 2: Sunflower seedling emerging through cracks in the crust.

Plate 3 : Buckled sunflower seedlings that failed to emerge through a soil crust.

4.2.5 Estimation of seedling emergence from texture and percentage residue cover

In Section 4.1 the effect of crust strength on seedling emergence was discussed. It was found that seedling emergence decreased with increasing crust strength. Covering the soil with crop residue mulches reduced crust formation and its effect on seedling emergence. It was also found in Section 4.2.4 that the emergence of monocotyledons (wheat) through soil crusts differed significantly from the emergence of dicotyledons (sunflower and soybean). In Section 3.3 equations for the estimation of crust strength from silt plus clay and residue cover were derived (Equations 3.7 and 3.10). These findings suggest that the estimation of percentage seedling emergence (SE, %) can be estimated from texture and residue cover depending on the technique used to measure crust strength. When the relevant equations are combined the empirical equations that follow were obtained:

- penetration resistance

a) Monocotyledons:

$$SE (\%) = -17.47 * \{[0.000013 * (S+C)^3 - 0.0036 * (S+C)^2 + 0.1635 * (S+C)] * (1-0.0060 * RC)\} + 100 \quad (4.10)$$

b) Dicotyledons:

$$SE (\%) = -35.89 * \{[0.000013 * (S+C)^3 - 0.0036 * (S+C)^2 + 0.1635 * (S+C)] * (1-0.0060 * RC)\} + 100 \quad (4.11)$$

Where 1 – 0.0060 * RC = PRRF, the penetration resistance residue factor.
These equations are only valid for soils with silt plus clay content less than 25%. For soils with more than 25% clay content residue cover has no effect and RC should be taken as 0.

- Emergence force

a) Monocotyledons:

$$SE (\%) = -0.0189 * \{[-0.0255 * (S+C)^3 + 0.6064 * (S+C)^2 + 59.52 * (S+C)] * (1-d * RC)\} + 100 \quad (4.12)$$

a) Dicotyledons:

$$SE (\%) = -0.0414 * \{[-0.0255 * (S+C)^3 + 0.6064 * (S+C)^2 + 59.52 * (S+C)] * (1-d * RC)\} + 100 \quad (4.13)$$

Where 1 – d * RC = EFRF, the emergence force residue factor. The value of d should be taken as 0.005 for soils with less that 15 % clay content, and 0.007 for soils with more than 15 % clay.

4.3 Conclusions

The aim of this chapter was to determine the interaction between different rates of crop residue and crust strength with the emergence of seedlings. The conclusions can be summarized as follow:

- Soil crust strengths that were high enough to impede seedling emergence occurred when no crop residue mulches were applied to the soils. The crusts that formed reduced the emergence of soybean and sunflower seedlings more than wheat. This is in agreement with literature where it has been reported in general monocotyledon crops are less affected by crusting than the dicotyledon crops.

- The percentage seedling emergence of all crops decreases dramatically when the crust strength was higher than 0.7 MPa (penetration resistance) or 500 gf (emergence force). With crust strengths lower than 0.7 MPa or 500 gf there were little or no decrease in seedling emergence.

- Covering the soil surface with residue mulches was found to improve seedling emergence. Seedling emergence increased with increased residue cover. Residue mulch covers kept the soil wetter which resulted in lower crust strengths.

- The highest values of seedling emergence occurred in the more clayey soil F, can be attributed to the cracking, due to the physical activity of the clay, which enhanced emergence.

- Empirical equations were derived that can be used to estimate the expected percentage seedling emergence of monocotyledons and dicotyledons from silt plus clay and residue cover.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The objectives of this research were to determine the effect of texture on the susceptibility of different soils for crusting; to measure the emergence of some seedlings as affected by crusting and to evaluate the effect of different levels of crop residue cover on crusting of different soils.

The penetration resistance (PR, MPa), modulus of rupture (MOR, kPa) and emergence force (EF, gf) were used as indicators of crust strength. These three techniques showed a certain consistency in terms of the soil properties that affected their magnitude. It was concluded that any of the three techniques can be used to access the crust strength of soils.

Silt, clay, silt plus clay and organic matter content were found to be important factors influencing crusting. These findings are in agreement with those of Mannering (1967); Sharma & Agrawal (1980) and Bradford & Huang (1992). Silt and clay contents are responsible for the increasing the consistency of the soils and crust strength. Fine particles with high total surface areas increase the surface to surface attraction and cementation (Sharma & Agrawal, 1980). In this study higher amounts of organic matter decreased the crust strength of a soil.

The degree of crusting increased with increasing silt plus clay contents up to about 35 to 40% or clay content up to about 20 to 25%. Above these values the degree of crusting decreased because of the montmorrilonitic of clay, which resulted in cracking of the soil crust (soil F). It can be expected that in soils with less than 25% clay, increasing silt contents can result in higher crust strengths (Bradford & Huang, 1992). Despite the content of silt, increasing clay contents (> 25%) can result in stable structure and hence lower crust strengths (Ben-Hur *et al.*, 1985).

Soils C and D with silt plus clay contents between 30 and 35% were found to be highly susceptible for crusting. Soil F showed low values of crust strength due to the presence of swelling clays which shrink upon drying, resulting in a high degree of cracking.

From the coefficients of determination ($R^2 > 0.75$) of the relationships between silt, silt plus clay or clay and modulus of rupture, penetration resistance or emergence force, it was suggested that silt plus clay can be used to predict crust strength.

The degree of crop residue cover was also found to influence crusting properties of the soils. In general increasing the degree of crop residue cover lowered the crust strength of the soils. The crop residue mulch on the surface reduced crusting by dissipating the energy of raindrops. Crop residues also kept the soil moist for a longer period resulting in a lower crust strength. Ranaganatha & Satyanarayana (1970), Mehta & Prihar (1973) and Chaudhry & Das (1980) also reported similar findings. The effectiveness of surface mulches in reducing crust strength was found to be similar for all the non-cracking soils A to D, with less than 25 % clay. For soil F with more than 25 % clay and a high degree of cracking, crop residue mulches had no effect. More than 70 % soil cover by crop residues is highly effective in reducing crust strength.

The crust strength of the soils can be estimated from the silt plus clay (S+C, %) content and residue cover (RC, %) using Equations 3.7 and 3.10, depending on the method selected to assess crust strength which can be penetrometer resistance (PR, MPa) or emergence force (EF, gf).

For soils with < 25% clay:

$$PR = [0.000013 * (S+C)^3 - 0.0036 * (S+C)^2 + 0.1635 * (S+C)] * (1-0.006 * RC) \quad (3.7)$$

Or

$$EF = [-0.0255 * (S+C)^3 + 0.6064 * (S+C)^2 + 59.52 * (S+C)] * (1-d * RC) \quad (3.10)$$

With d-values = 0.005 for soils with less than 15 % clay and 0.007 for soils with more than 15 % clay. A mean d-value of 0.006 can be used.

In agreement with the findings of Chaudhry & Das (1980); Rathore *et al.* (1983) and Rapp *et al.* (1999) it was found that seedling emergence decreased with increasing crust strength. Values of crust strength lower than 0.7 MPa or 500 gf, measured by penetrometer resistance or emergence force respectively, can be classified as low, since little or no decrease in seedling emergence occurred below these values. No seedling emergence is expected to occur at crust strength values above 2 MPa or 2000 gf. These values can be considered critical for seedling emergence.

Wheat seedlings appeared to be less affected by crust strength than soybean and sunflower. This is because the emergence of monocotyledons with epigeal germination is considered much easier than the emergence of dicotyledons with epogeal germination. Further, the monocotyledons have a bullet shaped coleoptile which helps with the emergence of the plumule (Taylor, 1971; Fapohunda, 1986 and Sivaprasad & Sarma, 1987). The small and non-significant difference between emergence of soybean and sunflower seedlings is attributed to the ability of each seedling to emerge from a given soil environmental conditions.

The application of crop residue mulches ranging from 0 to 6 t/ha on the soil surface considerably improved the emergence of seedlings. A crop residue mulch at the soil surface helps to protect the soil against the impact of raindrops causing crust formation and also, through reduced evaporation keeps the soil crust moist longer (Ranganatha & Satyanarayana, 1979; Awadhwal & Thierstein, 1985).

The prediction of seedling emergence (SE, %) can be done from the silt (< 0.05 mm) plus clay (S+C, %) content and residue cover (RC, %) using the following equations:

- Penetration resistance

a) Monocotyledons:

$$SE (\%) = -17.47 * \{[0.000013 * (S+C)^3 - 0.0036 * (S+C)^2 + 0.1635 * (S+C)] * (1 - 0.006 * RC)\} + 100 \quad (4.10)$$

b) Dicotyledons:

$$SE (\%) = -35.89 * \{[0.000013 * (S+C)^3 - 0.0036 * (S+C)^2 + 0.1635 * (S+C)] * (1 - 0.006 * RC)\} + 100 \quad (4.11)$$

Where 1 – 0.006 * RC = PRRF, the penetration resistance residue factor.
These equations are only valid for soils with silt plus clay contents less than 25%. For soils with more than 25% swelling clays residue cover has no effect on emergence in which case RC should be taken as 0%.

- Emergence force

a) Monocotyledons:

$$SE (\%) = -0.0189 * \{[-0.0255 * (S+C)^3 + 0.6064 * (S+C)^2 + 59.52 * (S+C)] * (1-d * RC)\} + 100 \quad (4.12)$$

b) Dicotyledons:

$$SE (\%) = -0.0414 * \{[-0.0255 * (S+C)^3 + 0.6064 * (S+C)^2 + 59.52 * (S+C)] * (1-d * RC)\} + 100 \quad (4.13)$$

Where 1 – d * RC = EFRF, the emergence force residue factor. A value of d = 0.005 for soils with less that 15 % clay and 0.007 for soils with more than 15 % clay, should be used.

Research needs

This study dealt with the measurement and prediction of the susceptibility of 5 soils for crusting based on texture. The results showed that silt, silt plus clay and clay contents were found to be reliable for such predictions. The study also investigated crop residue mulching as a method to mitigate the effect of soil crusts. Crop residue mulches proved to be effective in preventing soil crusts or enhancing seedling emergence.

Owing to the small number of soils used in this study it is suggested that investigations on the susceptibility of soils for crusting should include more soils, with a wider range of silt and clay contents. This would help to determine the limits at which silt plus clay or clay contents offer maximum crust strength, more accurately. Soils with swelling and non-swelling clays should be included.

Although it is possible to minimize the effects of soil crusts using crop residue mulches, the farmers rarely use this practice because it frequently hampers the planting operations resulting in uneven emergence and sometimes reduced yields. Crop residue is also rather used to feed animals than for conserving soils. It is necessary to investigate other methods that are technically feasible and economically viable to reduce the problem of soil crusting and poor seedling emergence.

ABSTRACT

Large areas of cultivated soils throughout the world develop rainfall-induced soil crusts. The soil crusts are usually the cause of reduced seedling emergence. To have quantitative information on the factors influencing the development of surface crusts and on the influence of ameliorating treatments on crust strength is valuable.

The objectives of this study were firstly, to determine the influence of soil texture on the susceptibility of different soils for crusting; secondly, to quantify the effect of soil crusts on the emergence of wheat, sorghum, soybean and sunflower; and thirdly to determine the optimum level of crop residues that can be used as a mulch to mitigate the effect of soil crust strength.

Five soils ranging in texture from sand to loam were sampled from the surface (0 – 200 mm). The soil samples were used in four greenhouse pot experiments that were conducted to examine the effect of crust strength on seedling emergence. Separate pot experiments in the greenhouse were conducted to determine how particle size distribution was related to soil crust strength.

Regression analyses showed that silt, silt plus clay and clay contents were related to crust strength as indicated by modulus of rupture, penetration resistance and emergence force. All the relationships were of third order polynomial nature. The crust strength increased initially with increasing silt plus clay contents up to about 35 to 40 %, or clay contents up to about 25 %, then declined as a result of cracking that occurred upon drying.

The emergence of wheat, soybean and sunflower was little affected at crust strengths less than 0.7 Mpa or 500 gf when measured as penetration resistance and emergence force respectively. Above these values seedling emergence decreased linearly with increasing crust strength.

The emergence of wheat was less affected by soil crusting than the emergence of soybean and sunflower, This is because monocotyledons with coleoptile emerge easier through soil crusts than dicotyledons that need to push their cotyledons through. The small differences that were observed between soybean and sunflower depend on the ability of the seedlings to emerge through adverse soil conditions.

Wheat residue mulch rates, ranging from 3 to 6 ton/ha, effectively reduced crust strength and enhanced seedling emergence. All the relationships were linear. Empirical equations were proposed that can be used to estimate crust strength and seedling emergence from the percentages of silt plus clay and residue cover.

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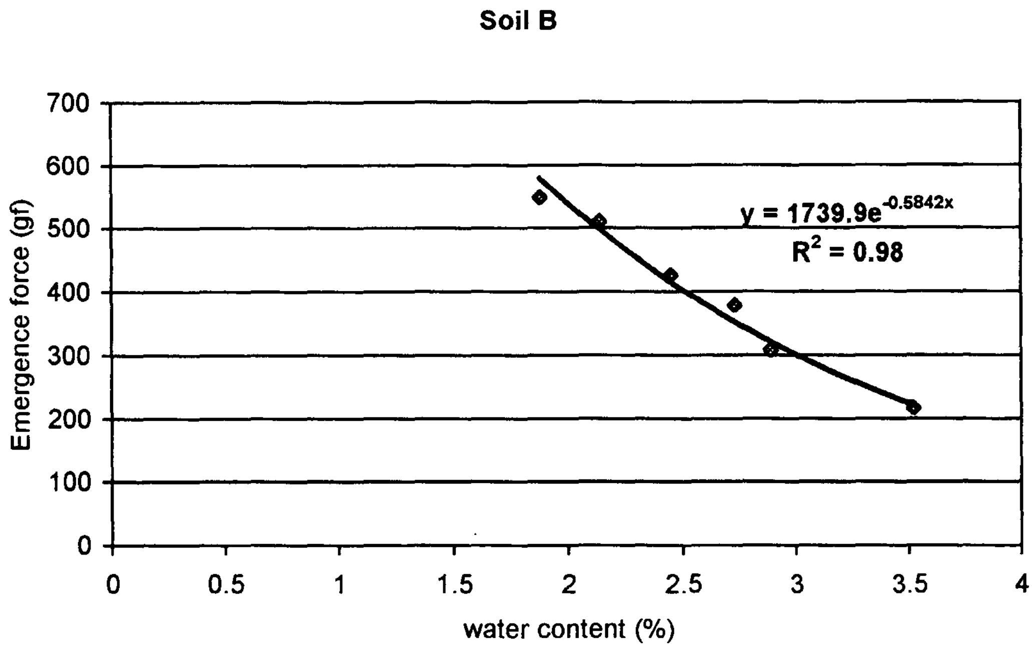
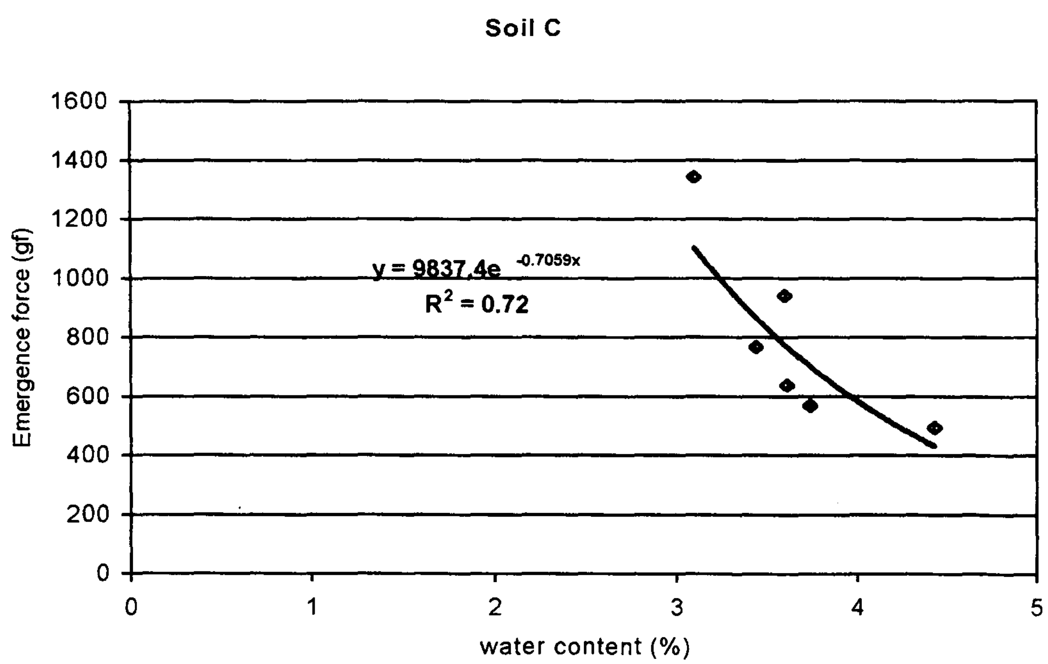
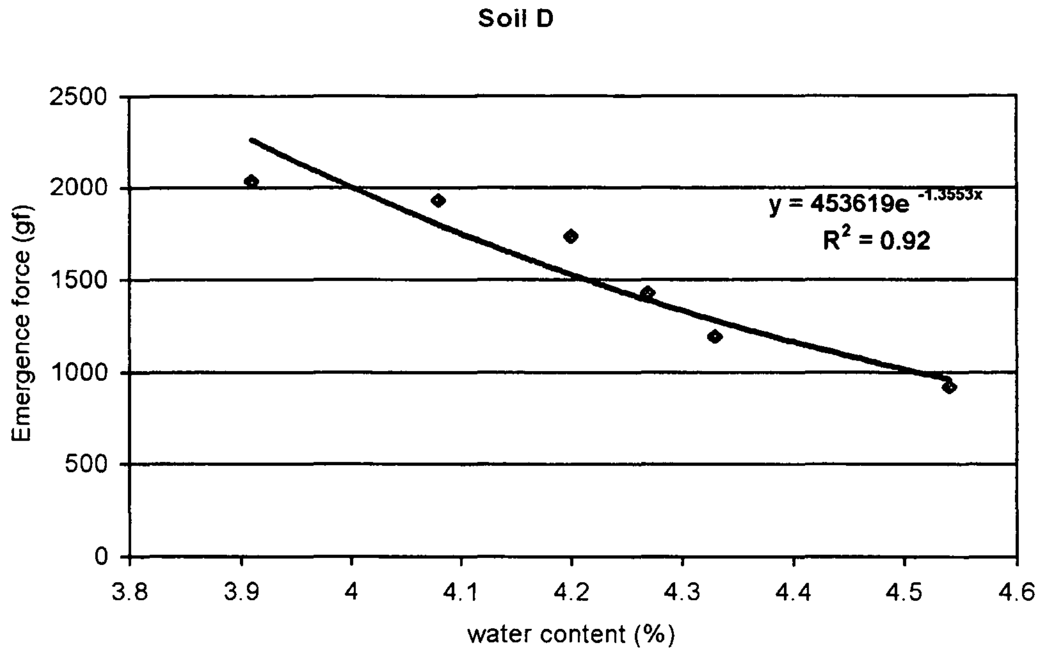
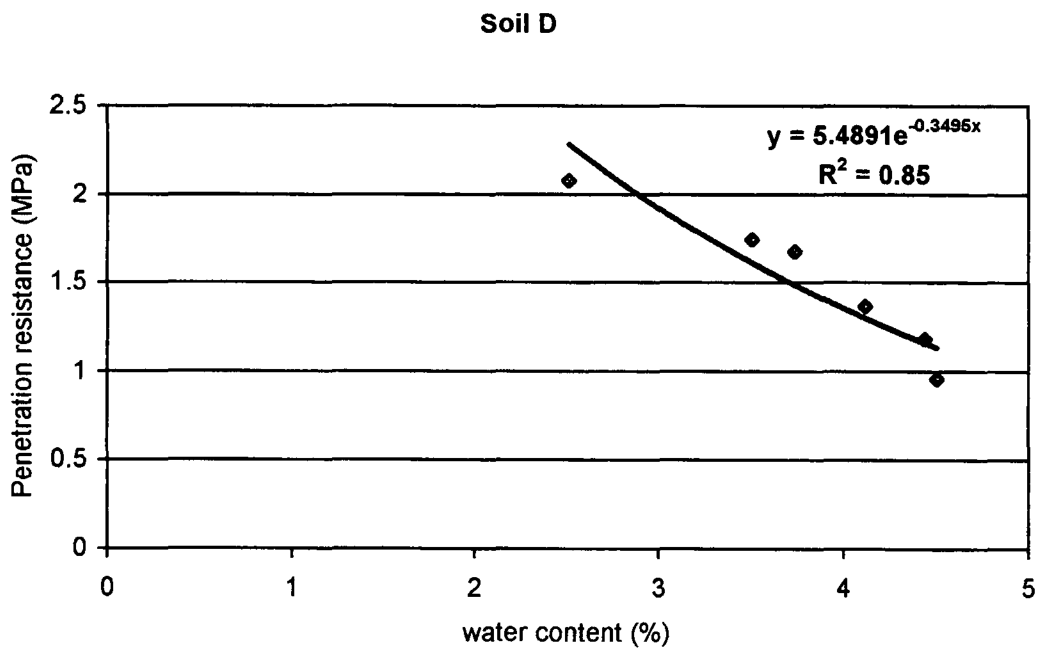
Appendix 3.1: Penetration resistance and water content relationships for each soil.



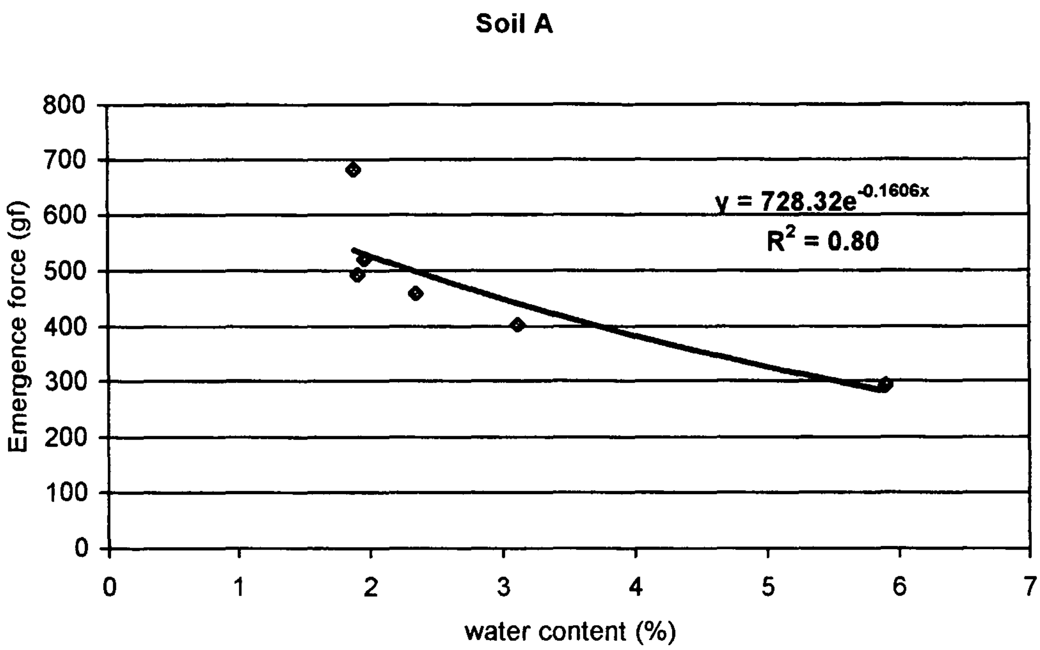


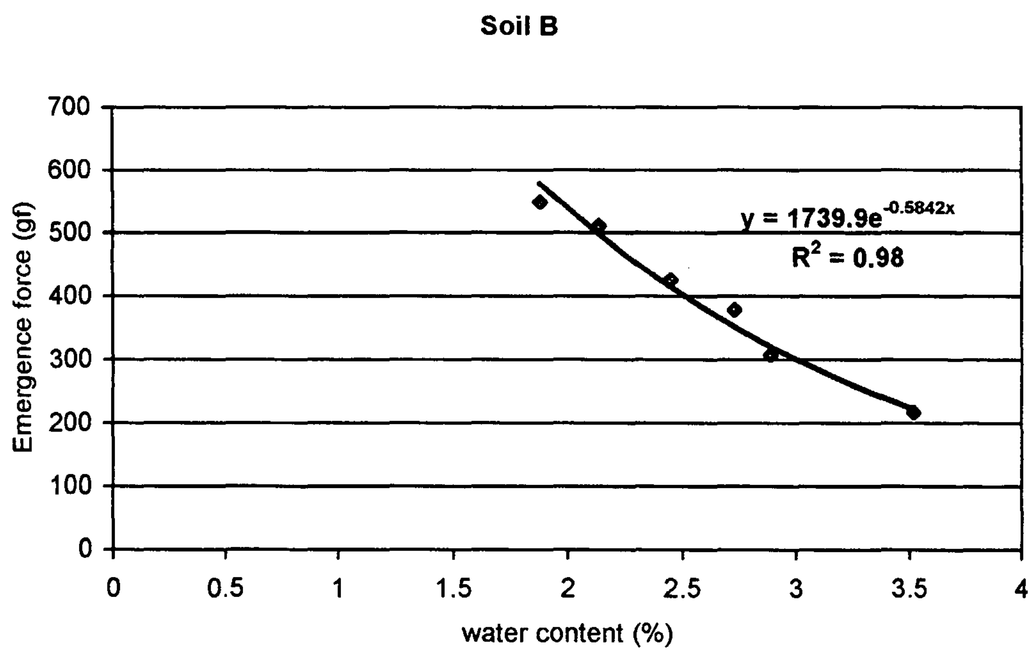
Appendix 3.1: Continued.



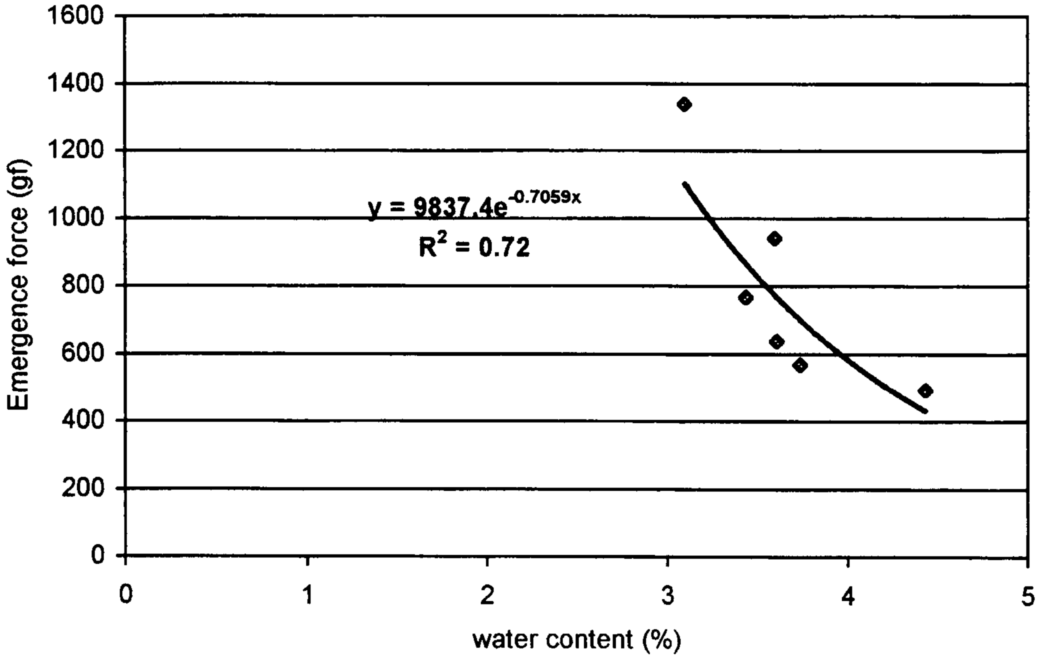


Appendix 3.2: Emergence force and water content relationships for each soil.



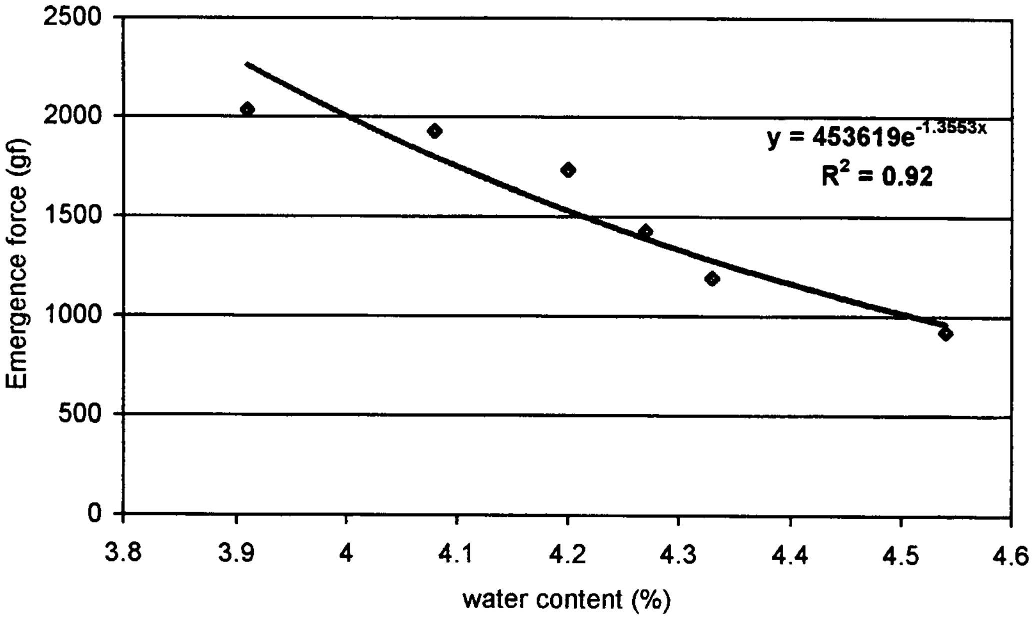


Soil C



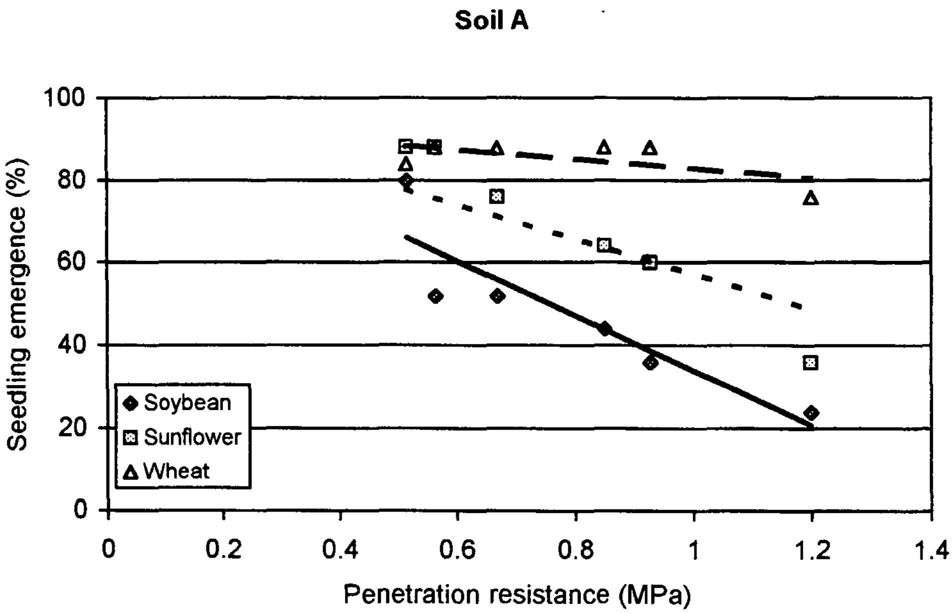
1600
1400
1200
1000
800
600
400
200
0
Emergence force (gf)
y = 9837.4e^-0.7059x
R^2 = 0.72
0
1
2
3
4
5
water content (%)

Soil D



2500
2000
1500
1000
500
0
Emergence force (gf)
y = 453619e^-1.3553x
R^2 = 0.92
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
water content (%)

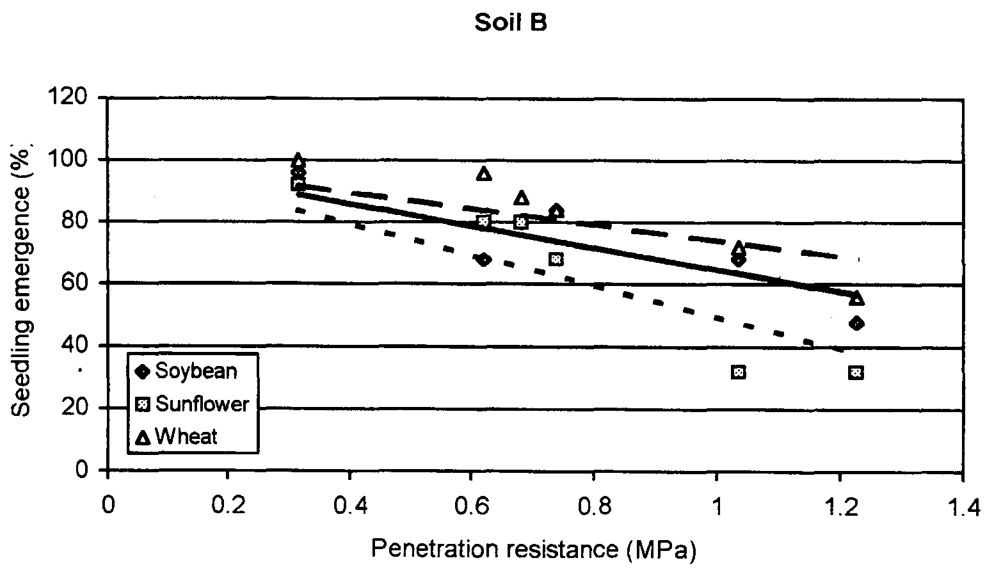
Appendices 4.1: Relationship between seedling emergence and penetration resistance.



Wheat: Y = -11.59 X + 94.46 $R^2 = 0.38$

Sunflower: Y =-42.81X + 100 $R^2 = 0.78$

Soybean: Y = -66.041X + 100 $R^2 = 0.81$

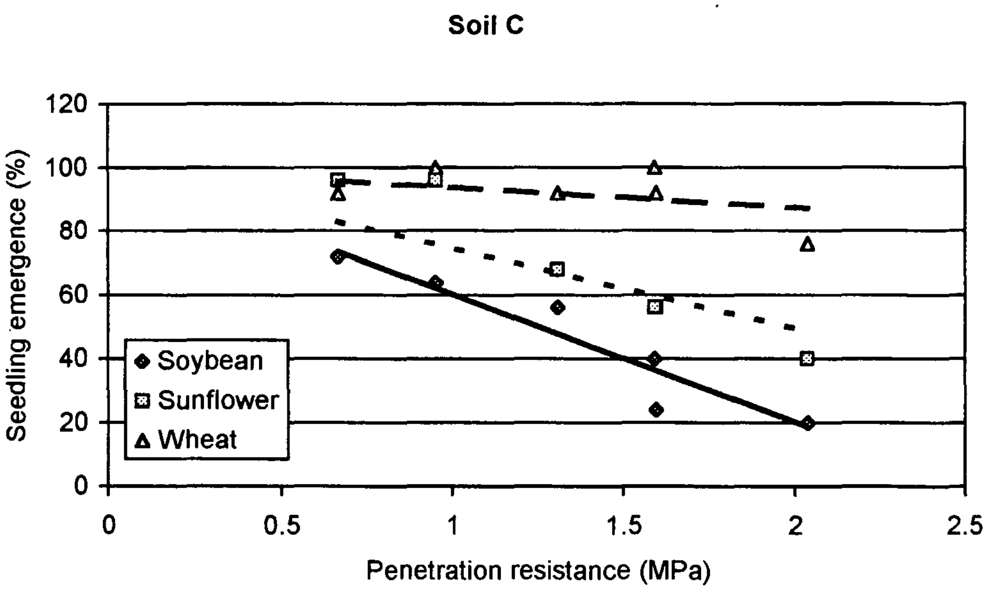


Wheat: Y = -25.90 X + 100.0 $R^2 = 0.38$

Sunflower: Y =-35.25X + 100 $R^2 = 0.73$

Soybean: Y = -50.61X + 100 $R^2 = 0.79$

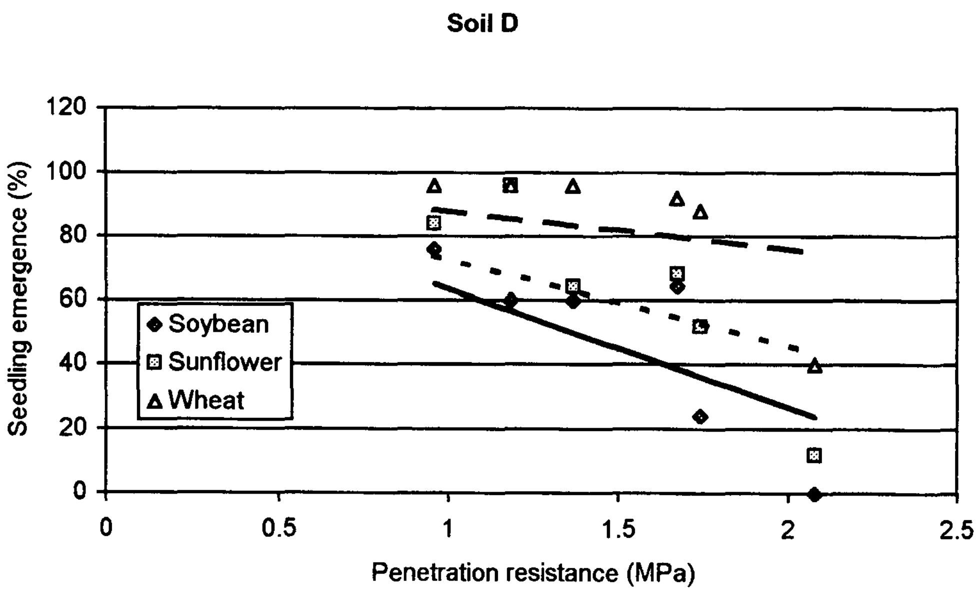
Appendices 4.1: Continued.



Wheat: Y = -12.06X + 100 $R^2 = 0.28$

Sunflower: Y = 27.13X + 100 $R^2 = 0.51$

Soybean: Y= -36.63X + 100 $R^2 = 0.62$



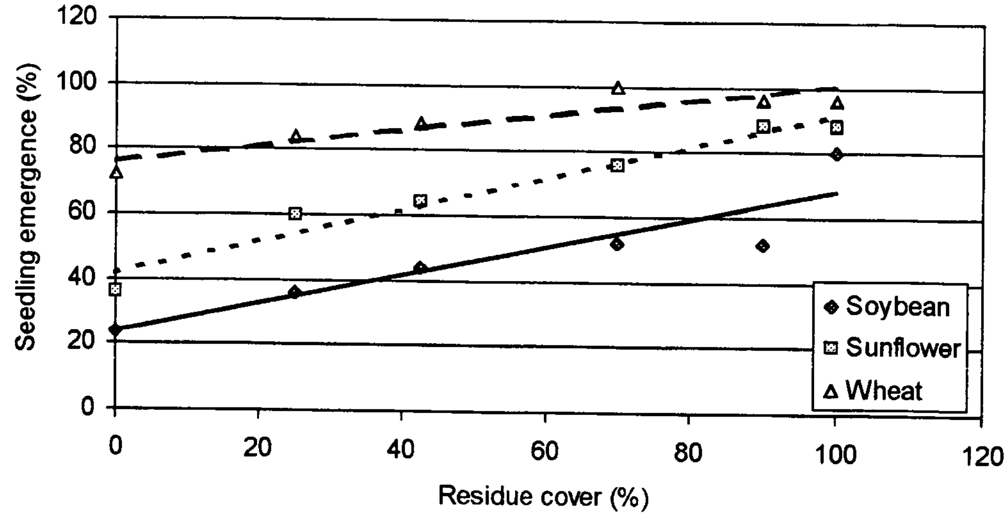
Wheat: Y = -6.301 + 100 $R^2 = 0.27$

Sunflower: Y = -25.29X + 100 $R^2 = 0.75$

Soybean: Y = -39.88X + 100 $R^2 = 0.89$

Appendices 4.2: Effect of emergence force on seedling emergence.

Soil A

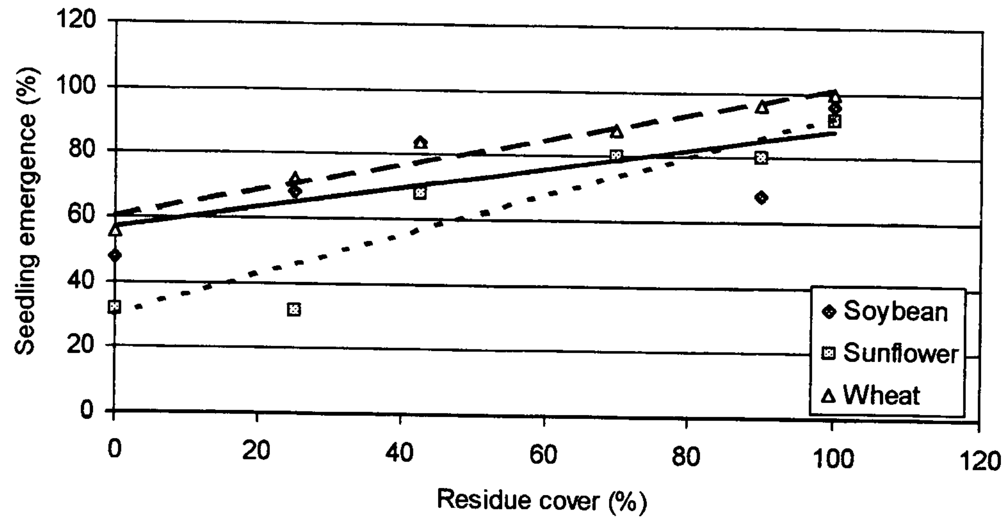


Wheat: Y = 0.2413X + 76.16 $R^2 = 0.83$

Sunflower: Y = 0.4460X + 23.65 $R^2 = 0.84$

Soybean: Y = 0.4992X + 41.42 $R^2 = 0.96$

Soil B

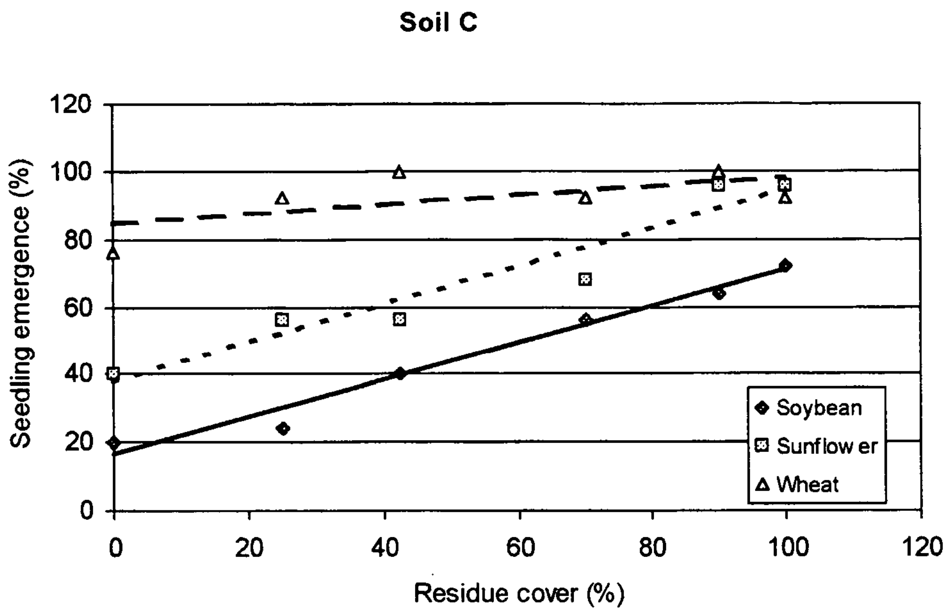


Wheat: Y = 0.4099X + 60.29 $R^2 = 0.95$

Sunflower: Y = 0.3117X + 56.99 $R^2 = 0.54$

Soybean: Y = 0.6261X + 29.83 $R^2 = 0.88$

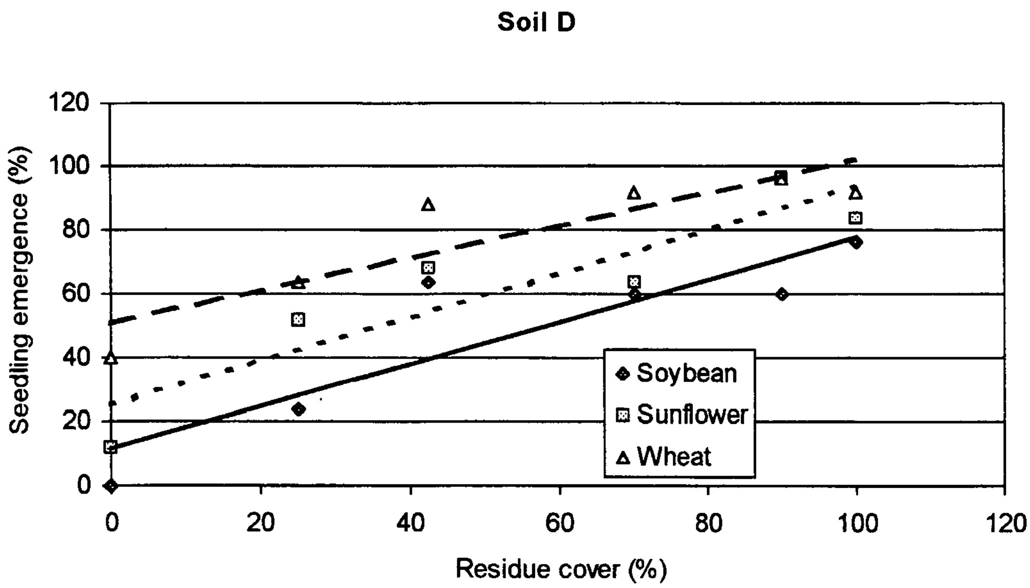
Appendices 4.2: Continued.



Wheat: Y = 0.1403X + 84.34 $R^2 = 0.38$

Sunflower: Y = 0.5680X + 37.66 $R^2 = 0.92$

Soybean: Y = 0.5447X + 16.27 $R^2 = 0.98$



Wheat: Y = 0.5105X + 50.80 $R^2 = 0.80$

Sunflower: Y = 0.6865X + 25.20 $R^2 = 0.83$

Soybean: Y = 0.6642X + 11.08 $R^2 = 0.79$