Influence of seed size and soil strength on emergence and early seedling establishment in a soil with hardsetting behavior

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Abstract: The study was conducted to compare the influence of seed size and soil strength on germination and emergence of cereal and legume seedlings in a hardsetting soil. The seed weights (g 100^{-1} seeds) of the plant species were 45.5 (maize), 4.5 (wheat), 2.5 (sorghum), 3.1 (oats), 0.54 (millet), 46.95 (bambaranut), 19.82 (cowpea), 3.13 (peas) and 45.14 (groundnut). Seedlings of each of the crop species were exposed to soil strengths of 1.2 and 2.4 kg /cm^2. This was achieved by sowing seeds at depths of 2.5 and 5.0 cm for 1.2 and 2.4 kg/cm^2 respectively. Emergence of seedlings was generally high in cereals (96%) than in legumes (56%). The emergence was in the order: sorghum (99.2%) > oats (96.7%) > millet (96.7%) > wheat (95.8%) > maize (87.5%) > cowpea (56.7%) > bambaranut (54.0%) > groundnut (34.2%) > pea (20.0%). The mean emergence percentage for the two soil strength levels were 88.0% and 52.5% for soil strengths of 1.2 kg/cm^2 and 2.4 kg/cm^2 respectively. Generally, cereal crops had higher emergence (87.6%) percentages than legumes (76.8%) in both soil strength levels. There was a significant negative correlation ($r=-0.88$, $p<0.05$) between soil strength and seedling emergence suggesting that poor emergence was caused by the high soil strength. It is suggested that the hypocotyl shape of the emerging cereal seedlings could have been able to exert much force in order to emerge from the strong soil. The study concluded that both seed weight and sowing depth should be considered when sowing seeds in a hardsetting soil if optimum germination and seedling establishment are to be achieved.

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Introduction

According to (Mullins *et al.,* 1987) hard setting soils are soils that set to a hard, structure less mass during drying and are thereafter difficult or impossible to cultivate until the profile is rewetted. Hard setting soils impose four agronomic limitations due to their high strength. First, the high strength of the dry soil can delay seedling emergence or tillage operation until the soil is sufficiently wetted by rainfall or irrigation; Secondly, even when there is sufficient power for tillage, it may not be possible to produce a suitable seedbed tilth; thirdly, crusting after sowing can prevent emergence and, finally drying of the profile by roots can impede their growth at potentials well above -1.5 MPa (Benjamin, 1982).

Soil strength is the capacity of a soil to withstand forces without experiencing failure, whether by rupture, fragmentation or flow; it is the ability to resist deformation and is a function of cohesive and frictional forces. Soil strength can be caused by pressure from traffic machinery (tractor wheels) and animal trampling or even heavy raindrops (Raghavan et al., 1990). Soil strength can influence emergence because the hard surface will prevent seedling emergence. In order to germinate and establish plants in a soil with a hard surface, it is first necessary to loosen it. With hardsetting soils, however, irrigation or rainfall after sowing can cause the surface to collapse again and even when no visible crust is formed, drying may cause the surface to harden sufficiently to prevent seedling emergence (Kirby, 1993; Yagmur and Kaydan, 2009; Odeleye and Olufolaji, 2010). Hardsetting is predominantly observed in soils with low concentration of organic matter (Mullins *et al*., 1987).

Hard setting soils are soils that set to a hard, structureless mass during drying and are thereafter difficult or impossible to cultivate until the profile is rewetted (Mullins *et al*., 1987). The Australian Soil Classification System (2002) has emphasized that hard setting soils are potentially the source of many physical limitations whose effects may be devastating or imperceptible, depending on the timing and intensity of rainfall or irrigation with respect to cultivation and development of the crop.

Shanmuganathan and Benjamin (1992) have shown that the soil surface capping in hardsetting soils can impede infiltration of water and prevent emergence of seedlings in both cereals and legumes. According to Loxton et al. (1984) a lot of soils in the North West Province have hard setting behavior. The deleterious effects of deep sowing on seedling emergence, growth and development of various crop species has been well documented in other soils (Kirby, 1993; Harris, 1996; Fowler et al., 1989; Nabi et al., 1987; Shanmuganathan and Benjamin, 1992). However, there is limited information of the effects of seed size and sowing depth on the seedling under the semi-arid environment of Soputh Africa, especially where soils display hardsetting behaviour. The objectives of this study were: (1) to compare different seed sizes and their influence on seedling emergence in a hard setting soil, and (2) to evaluate the effects of soil strength on emergence of seedlings of different species.

Materials and methods

Soil sampling and analysis

Soil was collected from uncultivated land in February 2009 at the Molelwane University farm located within 5 km of the city of Mafikeng (25°48' S, 25°38’ E) in the North West Province, South Africa. The soil was collected at a depth of 0-20 cm using a spade. It was then air-dried and passed through 2.0 mm sieve. It was analyzed for particle size distribution (Bouyoucos, 1962) and organic carbon (Walkley and Black, 1935). Soil pH was determined using a glass-calomel electrode in a 1:2,5 soil/water suspension (Soil Science Society of South Africa, 1990).

Experimental treatments and design

The experimental treatments consisted of a combination of nine seed weights (Table 1) and two levels of soil strength (1.2 and 2.4 kg cm^{-1}). The two levels of soil strength were achieved by sowing seeds at depths of 2.5 cm and 5.0 cm respectively. The eighteen (18) treatments were replicated six times in a randomized complete block design. Twenty seeds of each species were sown in PVC germination trays and placed in the glasshouse where temperatures varied between 19°C (night) and 34ºc (day). The trays were moistened to field capacity daily by using a mist spray of water

Table 1: Seed weight of the crop species used in the study.

Crop species	Scientific name	Cultivar / variety	Seed weight (g 100 $seed^{-1}$)
1.Maize	*Zea maize*	Pan 6528	45.5 ± 0.5
2.Wheat	*Triticum aestivum*	Kariga	4.5 ± 0.3
3.Sorghum	*Sorghum bicolour*	Pan 8446	2.5 ± 0.2
4.Oats	*Avena sativa*	Drakensburg	3.1± 0.4
5.Millet	*Panicum miliaceum*	SA-1	0.54 ± 0.1
6.Bambaranut	*Vigna subterranean*	SB19-3	46.95 ± 0.2
7.Cow pea	*Vigna unguigulata*	Pan 311	19.82 ± 0.6
8.Peas	*Pisum sativum*	Solara	32.13 ± 0.7
9.Groundnut	*Arachis hypogeae*	Pan 9212	45.14 ± 1.1

Numbers are means ± SD, n=10

Data collection

The seed size was estimated by determining the weight of 100 seeds of each of the nine crop species. The viability of seeds of each crop species was determined before starting the experiment by incubating fifty seeds of each crop species in a petri-dish at 27ºc. and calculating the germination percentage after 14 days. The strength of the soil at each depth was measured by using a hand held penetrometer (Wykeham Farrance Eng Ltd). The penetrometer was slowly inserted to the desired depth and the resistance was recorded. Immediately after recording the penetrometer resistance, a spatula was used to collect a sample of soil to the same depth in order to determine the gravimetric moisture content of the soil at the time of penetrometer reading. Measurements of penetrometer readings were made when the soil in each depth was visually in the driest state. In order to reach this state, soil watering was done after every seven days using a fine garden spray. The number of seeds that had emerged was counted daily in each treatment until no further emergence occurred. The soil was then excavated to retrieve the seeds that did not emerge and a tetrazolium test was done on them to establish whether they had rotted.

Analysis of data

Data was exposed to analysis of variance (AOV) using the Minitab statistical package on a computer (Ryan *et al*., 1983). Duncan's multiple range tests were used to separate the means of the treatments/crop species where significant differences existed (Duncan 1955). The percentages were transformed by using arcsine before using them in the ANOVA (SAS Institute Inc. 2000).

Results

The ANOVA (not presented) showed significant effects ($p<0.05$) of both seed weight and soil strength on the emergence of all the seedlings in all the species. The interactions were only significant ($p<0.05$) with respect to rotten seeds. Table 1 shows that seeds of leguminous species were generally bigger than those of cereals. *Zea mays* had the largest seed weight among the cereals while *Vigna subterranean* had the largest among the legumes. The variations among the leguminous species were not as large as those of cereals. The soil had a high content of sand and silt with very low organic matter (Table 2). This combination of properties makes it susceptible to hardsetting upon drying. The maximum penetrometer resistance reached in all the soils was high enough to adversely affect the growth of the epicotyls of all the crop species (Table 3). Generally, across the two levels of soil strength, there was a higher emergence among cereals (95.2%) compared to legumes (41.2%). The latter had higher proportions of non-emerged and rotten seeds/seedlings than the former. Within the classification of cereals and legumes, there were also significant differences ($p<0.05$) among the crop species. Table 4 shows that there was a higher proportion of and rotten seeds and non-emerged seedlings among leguminous species than cereals. It was observed that, although most of the seeds of the latter had germinated, however, they were smothered under the 'cap' of the hardsetting soil, especially at the higher level of soil strength (Table 5). Some of the cotyledons were torn and had soil particles clinging to them. There were large variations within the species in each soil strength level especially among the legume species. Table 6 shows that the emergence of seedlings among the crop species was different even within one level of soil strength. There were significant negative correlation coefficients between soil strength and seedling emergence ($r=-0.88$, $p<0.05$), soil water content and penetrometer resistance ($r=-0.74$, $P<0.05$) and seed weight and seedling emergence ($r-0.51$, $p<0.05$).

Table 2: Selected soil properties of soil used in the study

Property	Unit	Value
pH (H_2O)		5.7
Organic carbon	%	0.69
Particle size distribution		
Sand	%	59.9
Silt	%	31.6
Clay	%	8.5
Texture	Silty Loamy Sand	

Table 3: The maximum soil penetrometer resistance and water content reached in the different crop species

Crop species	Penetrometer resistance (kg/cm^2)	Water content (%)
Maize	1.07 ±. 2	1.79±. 3
Wheat	1.23 ±. 1	2.40±. 4
Sorghum	1.05±. 3	1.98±. 2
Oats	1.97 ±. 2	2.32±. 3
Millet	1.93± .4	3.02±. 4
Bambara nut	1.20±. 2	1.92±. 2
Cowpea	1.02±. 1	2.39±. 2
Pea	1.93±. 2	2.62±. 3
Groundnut	1.00 ±.1	2.30±. 1
Mean	*1.04*	*2.30*
SD	*0.33*	*0.62*

Numbers are means ± SD, n= 9

Table 4: Effect of seed weight of crop species on the percentages of emerged, non-emerged and rotten seeds across both levels of soil strength

Crop species	Emerged seedlings (%)	Non-emerged seedlings (%)	Rotten seeds/seedlings (%)
(a) Cereals			
Maize	87.5[b]	12.5[a]	0.0[a]
Wheat	95.8[bc]	3.3[a]	0.8[a]
Sorghum	99.2[c]	0.8[a]	0.0[a]
Oats	96.7[c]	3.3[a]	0.0[a]
Millet	96.7[c]	2.5[a]	0.8[a]
Mean	*95.18*	*4.48*	*0.32*
SD	*0.65*	*0.66*	*0.36*
(b) Legumes			
Bambara nut	54.0[a]	46.0[b]	0.0[a]
Cowpea	56.7[a]	40.8[b]	2.5[a]
Pea	20.0[d]	39.2[b]	40.8[b]
Groundnut	34.2[e]	64.2[c]	1.7[a]
Mean	*41.23*	*47.55*	*11.25*
SD	*1.02*	*0.92*	*1.05*

Means within a crop species with the same letter are not significantly different at the 5% probability level by Duncan's multiple range test.

Table 5: Effect of soil strength levels on the emergence, non-emerged and rotten seeds of the test crop species at two soil strengths.

Soil penetrometer resistance (kg/cm^2)	Seedlings Emerged (%)	Non-emerged seedlings (%)	Rotten Seeds/seedlings (%)
1.2	77.78[a]	17.78[a]	4.44[a]
2.4	64.59[b]	29.48[b]	5.93[a]
Mean ± SD	*71.19 ± 1.24*	*23.63 ± 1.2*	*5.19 ± .71*

Means within a column followed by the same letter are not significantly different at the 5% probability level by the LSD test

Table 6: Influence of soil strength on the emergence of seedlings of cereal and legume crop species.

Crop species	Soil strength (kg/cm^2)	
	1.2	**2.4**
(a) Cereals		
Maize	93.3[a]	81.7[a]
Wheat	96.7[a]	95.0[b]
Sorghum	100.0[a]	98.3[b]
Oats	100.0[a]	93.3[b]
Millet	100.0[a]	93.3[b]
Mean ± SD (n=5)	*98.0 ± 1.7*	*92.3 ± 2.5*
(b) Legumes		
Bambara nut	60.0[c]	48[b]
Cowpea	71.7[d]	41.7[b]
Pea	28.3[a]	11.7[b]
Groundnut	50.3[b]	18.3[a]
Mean ± SD (n=4)	*52.5 ± 4.3*	*29.9 ± 4.2*

Means within a row followed by the same letter are not significantly different at the 5% probability level by the Duncan's multiple range test.

Discussion and conclusions

The results in this study have shown that seeds that were sown at a depth of 5.0 cm experienced higher soil strength than those sown at 2.5 cm. This implies that seedlings of the latter required more force in order to push through the soil during emergence. Benjamin (1982) reported significant differences between the emergences of seedlings from two types of beans. Larger Amsoy seeds emerged very poorly at a depth of 64 mm compared to the smallest Amsoy seeds which emerged better at the same depth. Similar results were observed in this study where seeds of legumes with relatively larger seed weights showed poor emergence in both soil strengths while cereals, with smaller seed weights emerged better at both levels of soil strength. Similar results have been reported elsewhere (Karayel and Ozmerzi, 2008; Aikins and Afuakwa, 2008).

Benjamin (1982), Souty and Rodes (1993) and Madhi et al. (1998) have suggested that the shape and morphology of the tip of the emerging epicotyls could play a very important role in assisting the seedling to emerge through a soil. He suggested that the epicotyl of seedlings of the beans (*Phaseolus vulgare*) required much force to push through the soil than those of maize (*Zea mays*) due to their shapes. They ascribed the ability of the later to the sharp pointed nature of the epicotyl. Benjamin (1982) showed that although soil drying produces closer packing of soil particles, resulting in high soil strength, restriction of the strength to seedling emergence was closely related to the ability of the epicotyls to push through the surface crust created by the hardsetting soil. Benjamin (1982) thus concluded that deep sown seeds would be expected to take longer to emerge and species with small seed weights would not have the ability to penetrate through a deep layer of the soil. This inability could also be due to insufficient stored materials to generate the osmotic gradient necessary to overcome the pressure exerted by the soil or that the seedling might be too weak to withstand the forces necessary to overcome the resistance of the soil, with the hypocotyls breaking as it drags the cotyledon through the soil. This is consistent with the suggestion of several authors (Burris et al., 1973; Lafond and Baker, 1986; Edwards and Hartwig, 1971; Singh et al., 1972; Tisdall, 1996) who indicated that a hard soil below or above the seed might restrict seedling establishment especially where seeds are small and can only exert a small force to push through hard soil.

The results of this study have shown strong interactions between crop species and soil strength levels suggesting that as the depth of sowing increased, the ability for the seedling to emerge also depended on the crop species. Lafond and Baker (1986), Singh et al. (1972) have shown that seedlings of cereal crop species emerged better at both depths of sowing (soil strengths) than legume species. There were however differences within the cereal and legume species as was also the case with their seed sizes (weights). The application of these results is that crop species have to be sown at the appropriate depth in order to obtain good emergence in a hardsetting soil. This may involve the proper matching of the soil strength with the seed size.

The study has shown that hardsetting soils can contribute towards reducing the establishment of crop seedlings due to high soil strength that develops during drying. The results have revealed that seedlings of cereal species perform better than leguminous ones with respect to emergence and early establishment. This difference was attributed mostly to differences in the shape of the coleoptiles of the seedlings and the axial force that could be applied to grow through the strong soil. As Tamet et al. (1996) have suggested, temperature and moisture content of the soil could also play an important role on germination and emergence of the seedlings and thus need to be investigated in future studies. It is recommended that the soil strength should be kept to a minimum during emergence of seedlings by placing the seeds at a lower depth in hardsetting soils.

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