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CHAPTER 6

GROUNDNUT SEEDLING SURVIVAL IN ACID SOILS AS AFFECTED BY SEED PELLETING OR PRIMING WITH CALCIUM

6.1 INTRODUCTION

Growth of groundnut in soils with pH values below 5.3 is poor due to nutrient deficiencies or toxicities associated with low pH stress. In highly weathered soils, soil solutions tend to be low in nutrient cations, including Ca (Bell & Gillman, 1978; Isbell, 1978). Consequently, Ca deficiency is a common problem even for plants with low Ca requirements (Juo & Uzu, 1977). The susceptibility of legumes to soil borne fungi is higher in soils with low Ca content, resulting in poor establishment (Bateman & Lumsden, 1965). For groundnut production in acid soils, Ca is the essential element most commonly deficient (Gascho & Davis, 1994). While the most important consequences of Ca deficiency for groundnut productivity occur in the reproductive stages of development, some indications of Ca insufficiency may be evident in the vegetative stages of growth (Gascho & Davis, 1994). Low Ca concentrations in the soil as well as in the seed result in greatly reduced germination and seedling survival (Harris & Brolman, 1966; Adams & Hartzog, 1991). Poor germination and seedling survival were observed in sandy soils with Ca levels below 21 mg kg^{-1} in the upper 15 cm of the soil profile (Gascho & Davis, 1994). In Experiment 3 (Chapter 5), adequate Ca during germination considerably improved the survival rate of groundnut seedlings at low soil pH.

While liming may ameliorate most of the infertility factors associated with soil acidity (Foy, 1992), increasing the pH by liming is sometimes expensive or impractical, especially in low-input agriculture, thus warranting the need to look for alternative strategies to improve productivity on acid soils. Pelleting seeds with lime is a strategy often used to combat unfavourable soil conditions such as low pH (Loneragan *et al.,* 1955; Kumar Rao & Patil, 1977; Pijnenborg & Lie, 1990; McGuire & Hannaway, 1996). The practice of pelleting legume seeds with lime and the appropriate *rhizobia* is to provide a microenvironment around the seed more favourable for rhizobial survival, thereby improving legume production on acid soils. This practice is

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commonly used on soybeans, clover and alfalfa in order to ensure successful nitrogen fixation (Lowther, 1974; Cordero & Blair, 1978; Rice & Olsen, 1983; Pijnenborg & Lie, 1990; Spilde, 1997).

Seed pelleting is essentially a "seed coating" technique used primarily to improve the plantability of crops. The pelleting material is composed of an amalgam of fillers such as calcium carbonate, talc, clays, vermiculite etc., and cementing agents or binders such as various starches, sugars, gelatin, methyl cellulose, waxes, gum arabic, polyvinyl alcohol or even water (Cordero & Blair, 1978; Desai *et al*, 1997). The advantage of pelleting is that beneficial compounds can be incorporated into the pellet, while the major disadvantage is the tendency for the pellet to dry out under low moisture conditions, halting germination. Baker & Hatton (1987) documented that coating rice seed with calcium peroxide increased germination and plant establishment. In their various forms, seed coatings have become an important part of modern agriculture, and some have been shown to improve emergence and seedling growth in agronomic crops (Mikkelsen, 1981; McGuire & Hannaway, 1996; Spilde, 1997).

Seed priming or osmoconditioning, is a water-based process that is carried out on seeds to increase uniformity of germination and emergence, and enhance plant establishment. It entails the partial germination of seeds by soaking them in water (or in a solution of salts) for a specified period of time, and then re-drying them just before the radical emerges (Copeland & McDonald, 1995; Desai *et al*, 1997). Priming stimulates many of the metabolic processes involved with the early phases of germination. Given that part of the germination process has already been initiated, seedlings from primed seeds emerge faster, grow more vigorously, and perform better in adverse conditions (Baker & Hatton, 1987; Desai *et al*, 1997). The duration of the emergence period is decreased, leading to a more uniform plant stand (Mikkelsen, 1981; Baker & Hatton, 1987).

While pelleting or enriching seed with nutrients have been successfully practiced on some agronomic crops (Mikkelsen, 1981; McGuire & Hannaway, 1996; Spilde, 1997), information on effects of the techniques on groundnut is scant. Chapter 5 showed seedling survival is severely reduced at low soil pH. Haller (1983) observed that it was imperative for sweet clover and alfalfa to germinate in a neutral medium if reasonable yields were to be achieved on strongly acid

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soils (pH<4.0). This study was thus designed to determine the value of coating seed with Ca (pelleting) or fortifying it with Ca (priming) in improving germination and seedling growth of groundnut in acidified sand culture or in an acid soil in the field. The study hypothesized that pelleting or fortifying (priming) groundnut seed with Ca can provide sufficient Ca to ameliorate the adverse effects of acidification in the sensitive seedling stage, and that the benefit of Ca pelleting or priming on seedling survival would be due to counteraction of acidity in the vicinity of the germinating seed, in addition to the improved supply of calcium to the seed. This hypothesis was based on previous observations that both germination and seedling survival were improved as the Ca concentrations and pH values were increased (see Chapter 5).

6.2 MATERIALS AND METHODS

The effect of Ca pelleting or Ca priming on the seedling survival of groundnut was studied in two experiments conducted in growth chambers at the University of Pretoria. The validity of the data obtained in the growth chamber studies was investigated by conducting a third experiment in the field at the University of Pretoria Experimental Farm.

6.2.1 SEED PREPARATION

Seed priming

Ca solutions were prepared by dissolving the appropriate quantity of each Ca source in 500 ml of water. To ensure that the Ca-material was thoroughly dissolved, the solution was placed on a shaker for 10 minutes or until completely dissolved. Seeds were imbibed for 2½ hours in the Ca solutions, after which they were spread out on paper towels to dry in the shade for 48 hrs.

Seed pelleting

The pelleting technique entailed dilution of 100ml of a 3% non-ionic wetting and sticking agent (*Sandovit*) in 300 ml of water, and thoroughly mixing the solution using a magnetic stirrer. Seeds were wetted with the sticky solution before being rolled in lime or gypsum, encasing the seed in a thick coating. The seeds were spread out on paper towels to dry. To minimize flaking of the pellet the seed was planted one hour after treatment.

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6.2.2 TREATMENTS AND EXPERIMENTAL MANAGEMENT

EXPERIMENT 1

The experiment evaluated the effect of priming and pelleting seed with various Ca sources on seedling survival of groundnut grown in growth chambers at 27^{o}C and 100% relative humidity under a 16-hr photoperiod. The treatments used in the experiment are shown in Table 6.1, and they were arranged in a randomised complete block design with four replications.

Table 6.1 Description of the treatments used in Experiments 1 and 2.

Experiment 1	Experiment 2
1. Seed primed with 500 µM $CaSO_4$	1. Seed primed with 250 µM $CaSO_4$
2. Seed primed with 500 µM $CaCl_2$	2. Seed primed with 625 µM $CaSO_4$
3. Seed primed with 500 µM $Ca(NO_3)_2$	3. Seed primed with 1000 µM $CaSO_4$
4. Seed primed with 500 µM Calcimax**	4. Seed pelleted with 50 mg kg^{-1} $CaSO_4$
5. Seed pelleted with 50 mg kg^{-1} $Ca(SO_4)$	5. Seed pelleted with 50 mg kg^{-1} $CaCO_3$
6. Seed pelleted with 50 mg kg^{-1} $CaCO_3$	6. Control
7. Control	

**Calcimax is an organic chelate containing 8% Ca.

Seeds of cultivar *Kwarts* were planted in acid-washed sand contained in 35 x 30 x 15 cm deep seedling trays. The sterilized sand was moistened with a dilute nutrient solution whose composition was (µ*M*): 250 K, 250 N, 400S, 100 Mg, 10 Fe (as EDTA), 10 Cl, 3B, 0.25 Zn, 0.10 Mn, 0.07Cu and 0.02 Mo. This solution had a pH of 6.5, and was titrated with 0.1*M* H_2SO_4 to obtain two treatment pH values, namely pH 4.0 and pH 5.5.

The seedlings were allowed to grow for 21 days during which seedling mortality was assessed at 7-day intervals. At 21 days after emergence the surviving healthy plants were harvested, and roots were separated from the tops. The plant tops and roots were oven-dried at 80^{o} C for 48 hrs to determine dry mass.

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EXPERIMENT 2

The experiment evaluated the effect of priming seed with $CaSO_4$ at various Ca concentrations or pelleting with $CaCO_3$ on seedling survival of groundnut grown at pH 4.0 and pH 5.5 in growth chambers set at 30^{o}C and 100% relative humidity under a 16-hr photoperiod. The treatments used in Experiment 2 are given in Table 6.1, and the experimental design and procedure were similar to those in Experiment 1. Seeds of cultivar *Falcon* were used in Experiment 2.

In addition to the seedling survival test, early growth rate of the seedlings was determined by planting batches of 100 seeds per treatment at 5 cm depth in sterilised sand in seedling trays. Hypocotyl and taproot elongation were determined on healthy normal seedlings after four days. The hypocotyl and taproot elongation tests were not replicated.

The seedlings were allowed to grow for 21 days during which seedling mortality was assessed at 7-day intervals. At 21 days after emergence, the surviving healthy plants were harvested, and roots were separated from their tops. The plant tops and roots were oven-dried at 80^{o} C for 48 hrs to determine dry mass. Root length and root surface area were estimated using a GLS root scanner (HP Scanjet 3C). The roots were classified into three diameter categories: (a) roots with diameter <1.0 mm, (b) roots with diameter 1.0 – 2.0 mm, and (c) roots with diameter >2.0 mm. The root surface area was measured in mm^2.

EXPERIMENT 3

The experiment evaluated the effect of seed pelleting and priming on seedling survival and early growth of groundnut in the field. The treated seeds (Table 6.2) were planted in an acid sand clay loam at the Hatfield Experimental Farm of the University of Pretoria. The pH (KCl) of this soil was 4.8. The soil is classified as mesotrophic, luvic dark red brown soil of the Hutton form (Soil Classification Group, 1991) and by the USDA Soil Taxonomy System (Soil Survey Staff, 1990), as loamy, mixed, thermic Rhodic Kaundidalf (Nel *et al.,* 1996). Cultivar *Kwarts* was planted in plots that comprised of two rows, each 1m long, on 7 February 2002, while *Falcon* was planted in similar plots on 21 February 2002. The plots were arranged in a randomised complete block design replicated eight times.

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The surviving plants of cultivar *Falcon* were harvested 28 days after emergence while those of cultivar *Kwarts* were harvested 42 days after emergence. The measurements taken for both cultivars at harvest included plant height (distance from the ground level to tip of the longest stem), number of leaves on main stem and on whole plant, leaf area and shoot dry mass. The plant tops and roots were oven-dried at 80^{o} C for 48 hrs to determine dry mass.

Data for all three experiments were analysed using the GLM procedure of the SAS program package (SAS Institute, 1996). Samples of the treated seeds were analysed for Ca concentrations at the Central Analytical Laboratories (Pty) Ltd, Pelindaba, RSA.

Table 6.2 Description of the treatments used in Experiment 3

Treatments	Treatment code
1. Seed primed with 1000 µM $CaSO_4$	G-1000 µM
2. Seed primed with 2500 µM $CaSO_4$	G-2500 µM
3. Seed primed with 1000 µM Calcimax**	C/max-1000 µM
4. Seed primed with 1000 µM $CaNO_3$	$CaNO_3$ µM
5. Seed pelleted with 100 mg kg^{-1} $CaSO_4$	Gypsum
6. Seed pelleted with 100 mg kg^{-1} $CaCO_3$	Lime
7. Control	Control

**Calcimax is an organic chelate containing 8% Ca.

6.3 RESULTS AND DISCUSSION

EXPERIMENT 1

At 7 days after emergence seedling survival at pH 4.0 was not affected by low solution pH, but survival gradually declined during the 21-day experimental period (Figure 6.1). The decline in seedling survival was at a slower rate for seeds pelleted or primed with Ca. When the seed was not treated with Ca, seedling survival was 92% at 7 days after emergence, and declined to 71% at 21 days after emergence. With the exception of the $CaCl_2$ treatment, all the other seed treatments had survival rates greater than 90% at 21days after emergence. The adverse effects of low pH on seedling survival were minimised when seed was either pelleted or primed with Ca.

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At pH 5.5, the seedling survival trend was similar to that observed at pH 4.0 (Figure 6.1). The lowest survival rates were observed in the control treatment (86%) and in the $CaCl_2$ treatment (89%). Seedling survival in the other treatments ranged between 94% and 100%, and pelleted seed tended to have higher survival rates compared to primed seed. It is interesting to note that even at this relatively favourable pH (pH 5.5) seedling survival was significantly improved by seed treatment with Ca.

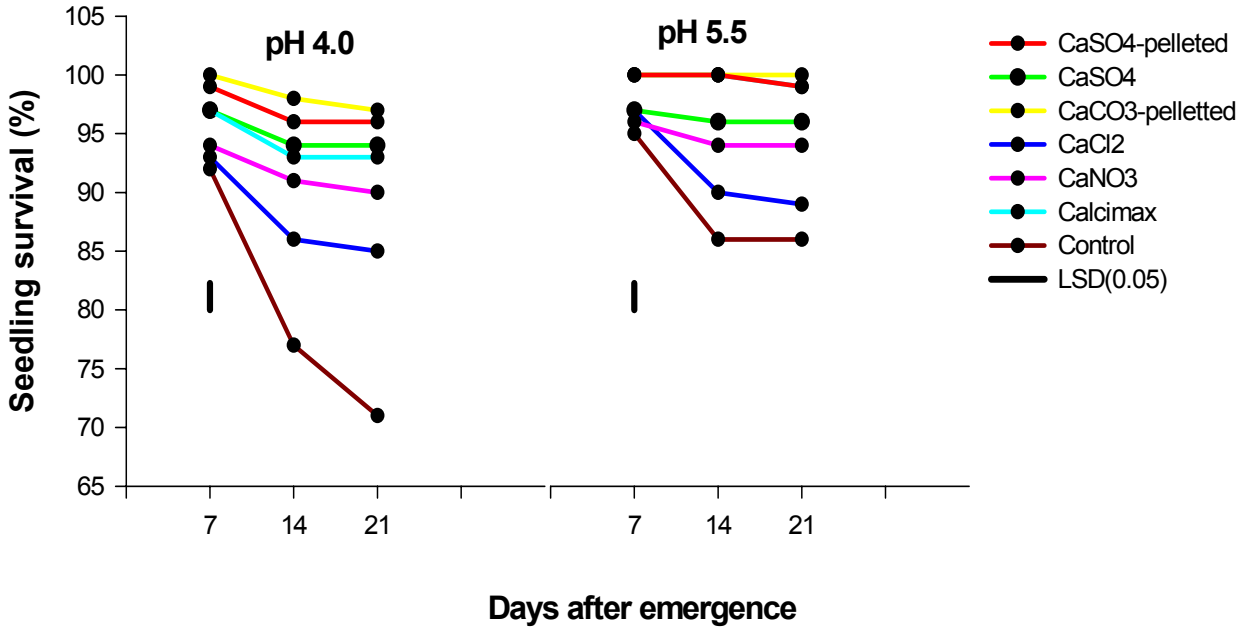

Figure 6.1 Effect of seed pelleting or priming on seedling survival at 7, 14 and 21 days after emergence -Experiment 1

Pelleting or priming the seed with Ca improved seedling growth (Figure 6.2). There was a significant interaction between Ca seed treatment and solution pH on shoot growth at 21 days after emergence (Table 6.3). For the control, calcimax and $CaCl_2$ treatments there were no improvements in shoot dry mass as the pH was increased from 4.0 to 5.5, but significant increases in dry mass were observed for the rest of the treatments. At pH 4.0, the shoot dry mass ranged from 0.24 g plant^{-1} in the control treatment to 0.42 g plant^{-1} in the gypsum pelleted treatment. At pH 5.5 the shoot dry mass in the control treatment was significantly lower (0.29 g plant^{-1}) than in all the other treatments except the $CaCl_2$ treatment. Thus, both pH and seed treatment had significant effects on shoot growth.

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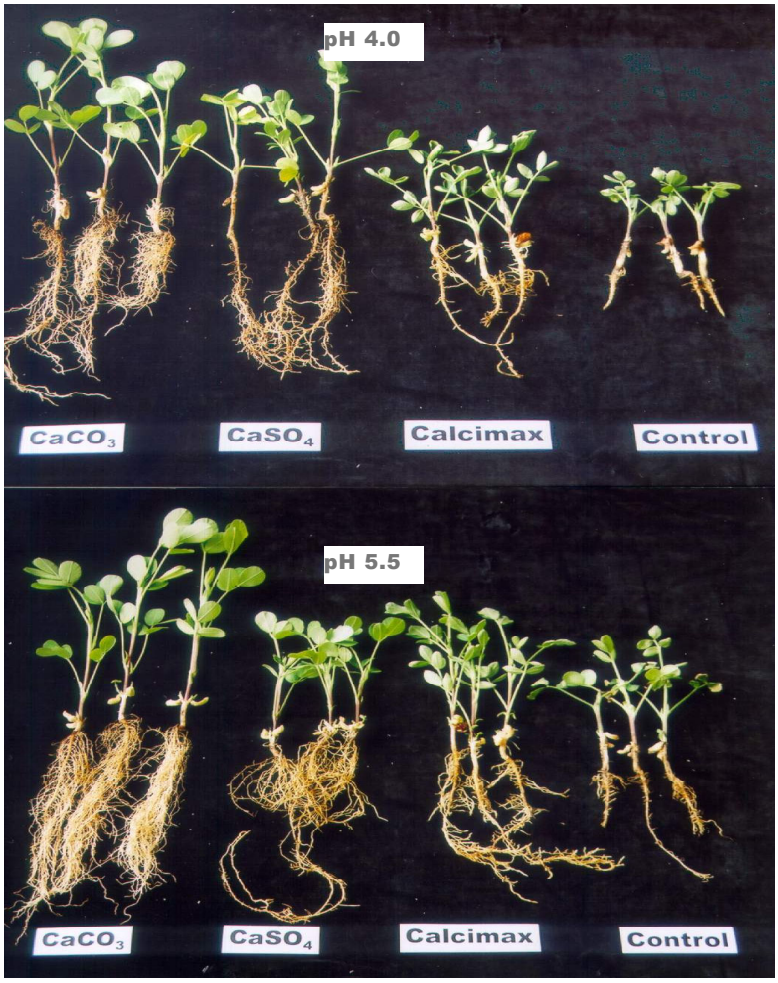

Figure 6.2 Effect of pelleting or priming seed with Ca on growth of seedlings at pH 4.0 or 5.5.

In general, pelleting the seed attained the highest increases in shoot dry mass at both pH levels, with similar values being observed whether the seed was pelleted with lime or gypsum. Pelleting or priming the seeds appeared to improve shoot growth more at pH 5.5 than at pH 4.0. This differential effect could be attributed to improved nutrient availability associated with favorable pH. Improved availability of Ca would result in improved root growth, since Ca is involved in cell division and cell elongation (Hertel, 1983). The detrimental effects of low pH on root capacity to absorb nutrients can explain the inhibited growth at pH 4.0, since excess H^+ ions interfere with ion transport and uptake, and the membranes of plant roots exposed to low pH for a long time become leaky, resulting in the loss of already absorbed nutrients (Foy, 1992).

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Table 6.3 Effect of Ca-treatment on shoot and root dry mass and shoot:root ratio of groundnut at 21 days after emergence

Treatment	Shoot dry mass ($g\ plant^{-1}$)		Root dry mass ($g\ plant^{-1}$)		Shoot:root ratio	
	pH 4.0	**pH 5.5**	**pH 4.0**	**pH 5.5**	**pH 4.0**	**pH 5.5**
1. $CaSO_4$	0.308	0.456	0.081	0.103	4.1	4.4
2. $CaCl_2$	0.285	0.322	0.083	0.082	3.4	3.9
3. $Ca(NO_3)_2$	0.306	0.463	0.080	0.082	3.9	5.6
4. Calcimax	0.312	0.352	0.079	0.073	4.0	4.8
5. $Ca(SO_4)$ pellet	0.416	0.558	0.085	0.096	4.9	5.8
6. $CaCO_3$ pellet	0.409	0.631	0.080	0.106	5.1	5.9
7. Control	0.238	0.285	0.076	0.082	3.0	3.5
Mean	**0.325**	**0.438**	**0.081**	**0.089**	**4.1**	**4.8**
LSD $_{(0.05)}$ pH	*0.023*		*0.021*		*0.194*	
Ca-source	*0.043*		*0.013*		*0.428*	
pH x Ca-source	*0.061*		*0.036*		*0.512*	

The low survival rates and insignificant effects on shoot dry mass of seeds treated with $CaCl_2$ cannot be explained since chlorine toxicity has not been found in groundnut (Gascho & Davis, 1994). Studies with other legumes have pointed to the possibility of yield depressions due to chloride toxicity (Islam *et al.,* 1987). When they tested the response of plants to Ca concentrations with chloride or sulphate as counter-ion they observed that a number of dicotyledons (soybean, french bean, lupin, sunflower, safflower) exhibited large growth responses to a much higher range of solution Ca concentration when $CaSO_4$ was the source of Ca, compared to $CaCl_2$. They observed mild chlorosis of the lower leaves and yield depressions in soybean and french bean at 3000 µM $CaCl_2$, which they attributed to a possible calcium-induced Mg deficiency, since the same symptoms were not observed in the $CaSO_4$ treatment that had a higher solution Mg concentration.

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Irrespective of the seed treatment, the effect of solution pH on root dry mass was not significant, with root dry mass averaging 0.08 g plant^{-1} at pH 4.0, and 0.09 g plant^{-1} at pH 5.5 (Table 6.3). The less adverse effects of pH on root dry mass compared to shoot dry mass of legumes has been observed by other investigators (van Beusichem, 1982; Yan *et al.,* 1992). Tang & Thomson (1996) reported that root dry mass of a number of grain legume species responded to solution pH in a similar manner to shoot mass, but the effect of low pH on root weight was less than on shoot weight. This effect could be due to low pH triggering the plants to direct more assimilates to the roots than to the shoot system. Although pH did not affect root dry mass, pelleting or priming the seed resulted in non-significant increases in root dry mass of up to 12% at pH 4.0, and by up to 29% at pH 5.0, compared to the control treatment.

The ratio of shoot to root growth was significantly influenced by pH and by Ca treatment, with higher ratios being observed at pH 5.0 compared to pH 4.0 (Table 6.3). The shoot-root ratio at pH 4.0 was 3.0 in the control treatment, and 5.1 in the lime pelleting treatment. At pH 5.5, the shoot-root ratio increased from 3.5 in the control treatment to 5.9 in the lime pelleting treatment. Breeze *et al.* (1987) similarly observed that for white clover the shoot-root ratio was lower at pH 4.0 than at pH 5.0, 6.0 or 7.0. The lower ratios at low pH could be attributed to the partitioning of photosynthate between shoots and roots under nutrient-limiting conditions when roots become relatively stronger sinks for carbohydrate (Clarkson, 1984).

EXPERIMENT 2

In experiment 2, 100 germinating seeds per treatment were removed and measured for hypocotyl and taproot root elongation after four days, the results of which are presented in Table 6.4. The average length of the hypocotyls in the control treatment was 18mm at pH 4.0 and 19mm at pH 5.5. Seed pelleting resulted in improved hypocotyl development, with lengths of 25mm at pH 4.0 and 28.5mm at pH 5.5. In the primed treatments the hypocotyls were even longer at 31mm at pH 4.0 and 38 mm at pH 5.5. The taproots in the primed treatments had elongated up to 52mm at pH 4.0 and 66 mm at pH5.5, compared to 32 and 37mm at pH 4.0 and pH 5.5 respectively, in the control plots. The results showed a tendency for the hypocotyls and taproots of primed seeds to elongate at a faster rate than those of the pelleted seeds. This outcome would be expected, since many of the metabolic processes involved with the early phases of germination had already been

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initiated during priming. With a faster rate of hypocotyl elongation, the primed seeds emerged on the fourth day after planting, and by day six all the seedlings had emerged, whereas emergence in the other treatments was complete by day 10. From an agronomic standpoint, this means that the fortified seed will be less vulnerable to soil fungal and bacterial pathogens since it emerges faster, and can also lead to a more uniform plant stand. A uniform stand of healthy, vigorous plants is essential if the yields and quality needed for profitable groundnut production are to be achieved.

Table 6.4 Hypocotyl and taproot elongation at 4 days as affected by seed treatment

Treatment	Hypocotyl length (mm)		Taproot length (mm)	
	pH 4.0	pH 5.5	pH 4.0	pH 5.5
1. 250 µM $CaSO_4$ - F	26	31	46	57
2. 625 µM $CaSO_4$- F	30	37	52	63
3. 1000 µM $CaSO_4$- F	31	38	50	66
4. $CaSO_4$- P	25	29	47	59
5. $CaCO_3$- P	25	28	49	59
6. Control	18	19	32	37

The number of seedlings surviving at pH 4.0 tended to decline from 7 to 21 days after emergence (Figure 6.3). In the control treatment only 77% of the original number of seedlings survived up to 21 days after emergence, compared to 97% when the seed was pelleted with lime. Seedling survival in the primed treatments improved from 87% to 93% as the Ca concentration increased from 250 to 1000 µM. The decline in the number of seedlings surviving at pH 5.5 in the primed and pelleted treatments was of a lesser magnitude than at pH 4.0. In the control treatment survival of the seedlings declined from 92 to 85% (Figure 6.3). Significant effects of pH on seedling survival were observed when the seed was not treated with Ca, with improved survival being observed at pH 5.5 compared to pH 4.0.

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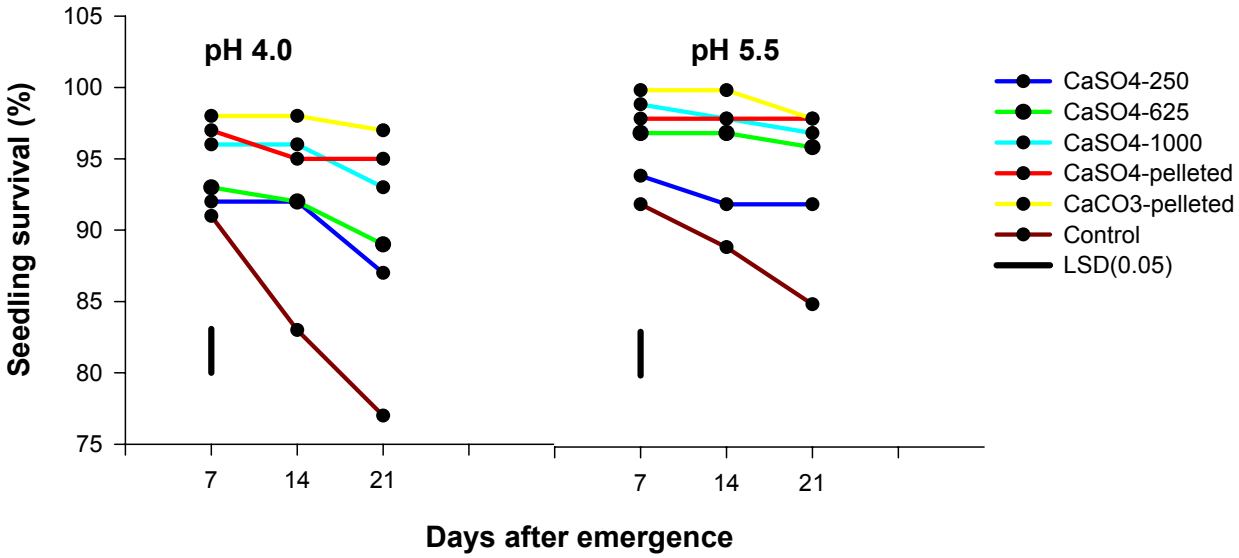

Figure 6.3 Effect of seed priming or pelleting on seedling survival (%) at 7, 14 and 21 days after emergence – Experiment 2

Overall, pelleting the seed with lime or gypsum resulted in the highest survival rates at both pH levels, and the harmful effects of pH were diminished when the seeds were either pelleted or primed with Ca. According to Asher (1987) legume seedlings rely on external Ca concentration at an early growth stage, because the seeds have low Ca content compared to the vegetative plant tissue (Welch, 1986), and Ca availability is low (Helms & Davis, 1973). Consequently, low Ca availability, coupled with low pH might inhibit plant emergence and establishment. Buerkert & Marschner (1992) postulated that the main effect of Ca supply on seedling survival of bean seedlings was to decrease exudation of amino acids and carbohydrates from seeds and seedlings. Exudates attract and activate zoospores, thereby resulting in increased fungal infection (Kuan & Erwin, 1980).

Seedling survival percentages showed that pelleting or priming seeds with small amounts of Ca sources appeared to provide sufficient Ca to enable groundnut seeds to establish well in acid soils. This observation was substantiated by an analysis of the primed seeds for Ca content, which showed increases in Ca content of 28% to 286% when seed was fortified with different concentrations and sources of Ca as shown in Table 6.5.

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Table 6.5 Effect of pelleting or priming seed on the seed Ca content

Treatment	% Ca content
$CaSO_4$ at 250 µM	0.09
$CaSO_4$ at 625 µM	0.09
$CaSO_4$ at 1000 µM	0.11
$CaSO_4$ at 2500 µM	0.21
Calcimax at 1000 µM	0.17
$CaNO_3$ at 1000 µM	0.17
$CaCO_3$ pelleted at 50 mg kg^{-1}	0.27
Untreated seed (control)	0.07

Priming the seed with Ca positively influenced plant growth, and the higher the Ca concentration the better the growth (Figure 6.4).

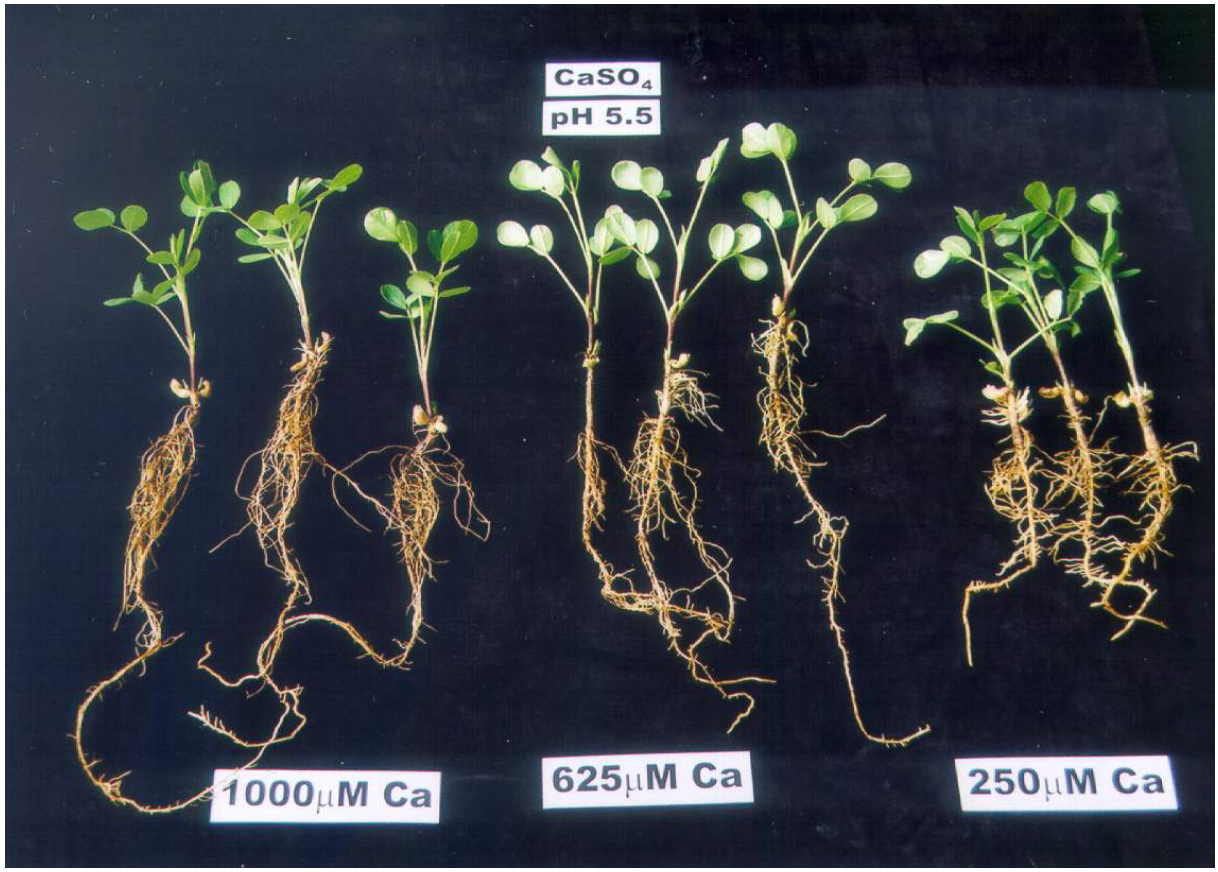

Figure 6.4 Seedling growth at 21 days after emergence as influenced by seed priming with gypsum at different Ca concentrations.

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Shoot dry mass 21 days after emergence was significantly affected by seed priming and pelleting, but not by pH (Figure 6.5). The increases in shoot dry mass due to pelleting were 381% at pH 4.0 and 293% at pH 5.5. Seed priming increased the shoot dry mass by up to 275% at pH 4.0 and 241% at pH 5.5. In the seed priming treatments, a significant interaction was observed between pH and Ca concentration. The interaction showed significant increases in shoot dry mass as the Ca concentrations increased at the higher pH level. Plants pelleted with either lime or gypsum produced similar dry mass at both pH levels.

The root dry mass responded to seed priming or pelleting and to pH in a similar manner to shoot dry mass (Figure 6.5). At pH 4.0, root dry mass was highest (0.11 g plant^{-1}) when the seed was pelleted with lime, and up to 0.08 g plant^{-1} when the seed was primed with 1000 µM Ca. In the priming treatments root dry mass increased as the Ca concentrations increased. The root dry mass was higher at pH 5.5 compared to pH 4.0, especially in the pelleted treatments and in primed treatments when Ca concentrations were 625 µM or greater. Plants in the pelleted treatments produced significantly higher root dry mass compared to those primed with 1000 µM Ca.

There was no response pattern in the ratio of shoot to root growth, though there was a slight trend towards increased ratios at pH 4.0 compared to pH 5.0. These results are at variance with observations in Experiment 1, and this could be attributed to the differences in conditions in the growth chambers where the experiments were conducted. Luxuriant vegetative growth of groundnut has been observed in controlled environment experiments under warm temperatures (Marshall *et al,* 1992) or low irradiance (Ketring, 1979). Talwar *et al.* (1999) attributed enhanced plant growth under high temperature (35/30 ^{o}C) to the development of alternative sinks. In this experiment, the temperature in the growth chambers was set at 30^{0} C and 100% relative humidity under a 16-hr photoperiod, thus providing optimal conditions for luxuriant vegetative growth, especially the pelleted treatments (Figure 6.6). This resulted in very high vegetative biomass which contributed to the low shoot to root ratios.

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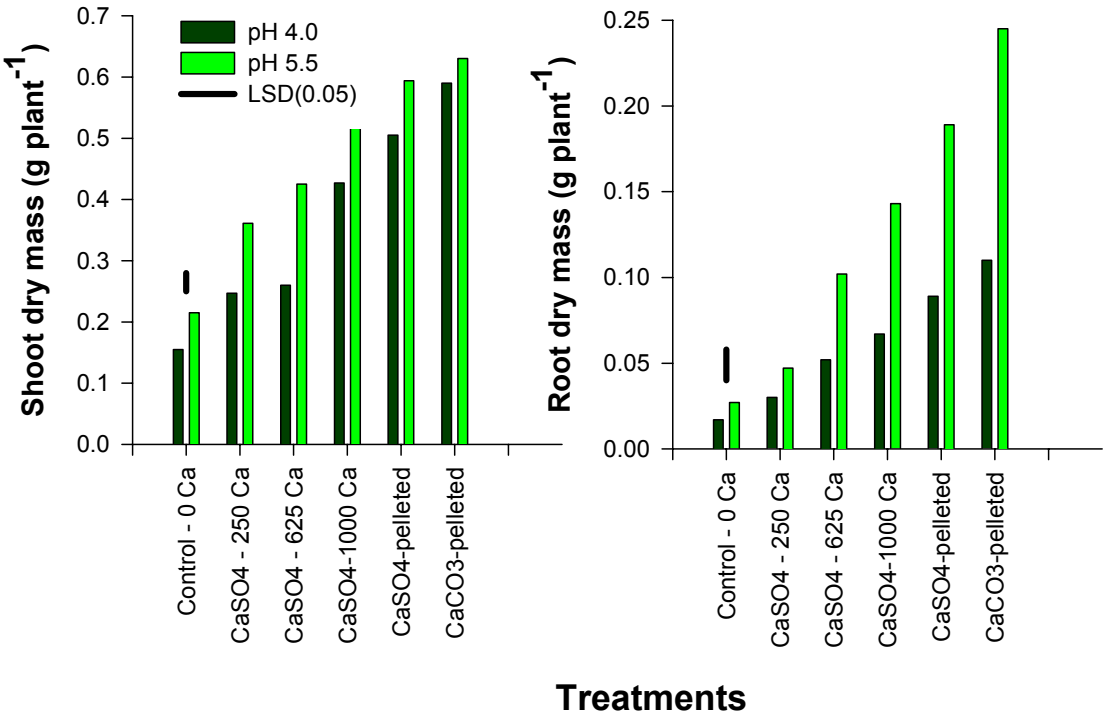

Figure 6.5 Effect of seed pelleting with $CaCO_3$ and seed priming with $CaSO_4$ on shoot and root dry mass at 21 days after emergence.

The total root length for plants grown at pH 4.0 was 230 mm per plant in the control treatment, and increased 29 times to 6530 mm for plants grown in the lime-pelleted treatment (Figure 6.7). At pH 5.5, the total root length of plants grown in the lime-pelleted treatment was 12530 mm. By comparison, plants pelleted with gypsum obtained a total root length of 6670 mm at the same pH level. At both pH levels, primed seeds did not have as good growth as pelleted seeds. Within the seed priming treatments, increasing the Ca concentrations from 250 to 1000 µM resulted in increases in root length of >300% at both pH levels. The interactive effects of pH and seed treatment on total root length were significant, with better root growth being observed at the higher pH level with the pelleted treatments. Pelleting the seed with gypsum resulted in better root growth than fortifying the seed with gypsum, even with 1000 µM.

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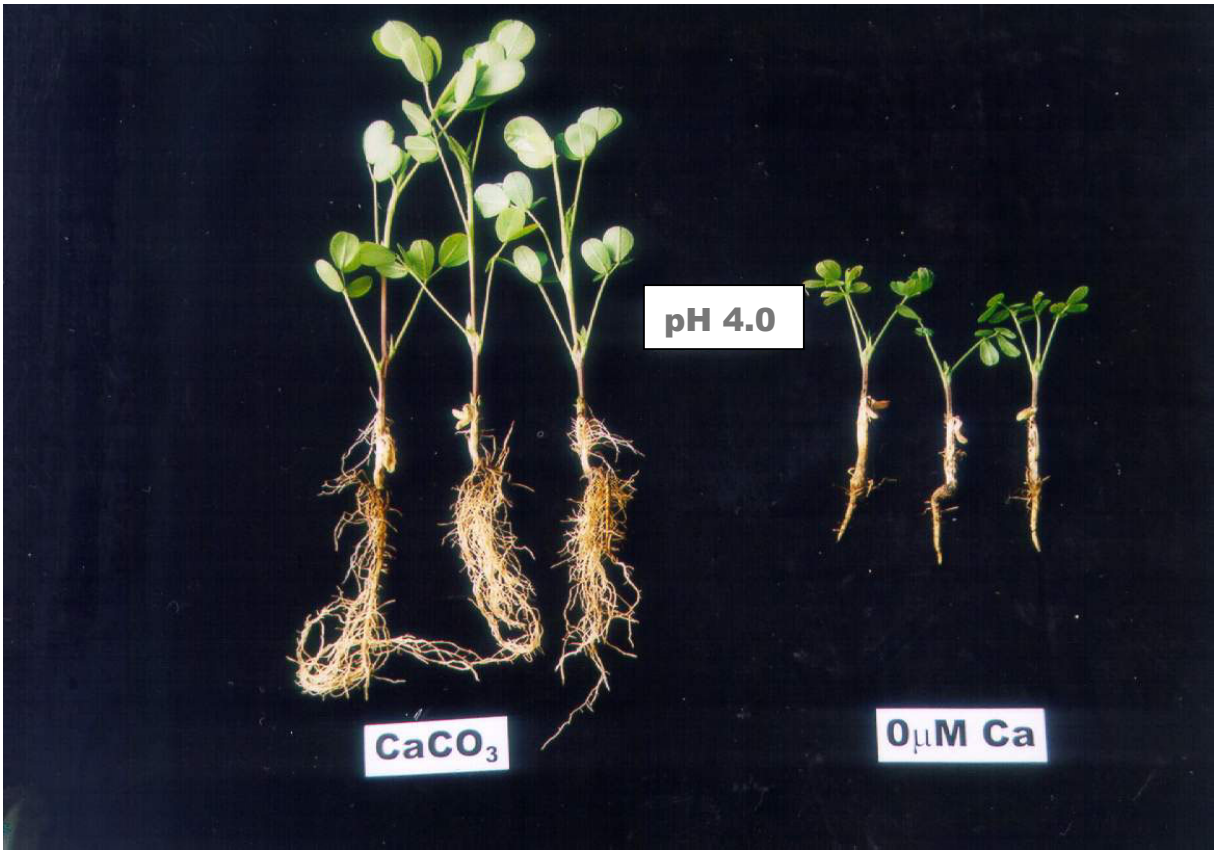

Figure 6.6 The effect of lime pelleting on seedling growth at pH 4.0 at 21 days after emergence.

Total root surface area per plant followed the same response trends as total root length (Figure 6.7). At pH 4.0, root surface area increased from 22mm^2 for plants of the control treatment to 220mm^2 for plants of the lime-pelleted treatment. Total root surface area also increased with increasing Ca concentrations in the primed treatments. At pH 5.5, the total root surface area was 396mm^2 in the lime-pelleted treatment compared to 35mm^2 in the control treatment. Overall, the root surface area increased as the pH was increased from pH 4.0 to 5.5. The increases in total root surface area were greater in the pelleted treatments compared to the primed treatments.

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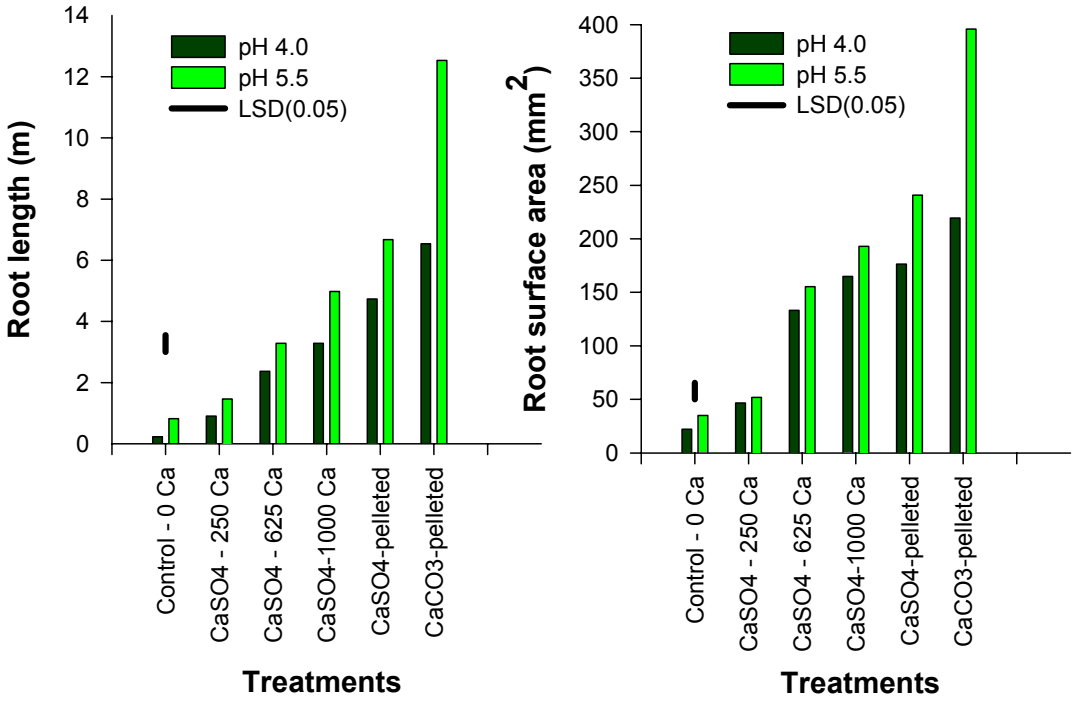

Figure 6.7 Effect of seed pelleting with $CaCO_3$ and seed priming with $CaSO_4$ on total root length and root surface area at 21 days after emergence.

Comparison of the priming versus pelleting effects on root development showed that the latter treatment was superior. The superiority of pelleting could be the result of a "liming effect" caused by the dissolution of lime or gypsum encasing the seed. This means that roots of the germinating seedlings pass through a band of "treated soil", which should facilitate better root growth. Determination of the pH of the soil solute after the plants were harvested at 21 days after emergence showed the pH values to be significantly higher in the pelleted treatments compared to the fortified treatments (Table 6.6). One can therefore deduce that pelleting, especially with lime improved the conditions for root growth in the microenvironment around the seed. In all the treatments the determined soil solute pH values were lower than the solution pH treatments, and this could partly be explained by the phenomenon of proton release in exchange for cations by roots, which results in acidification of the soil solution (Moore, 1974; Schubert *et al*, 1990). In addition, it is known that plants using NH_4^+ as a source of N decrease the pH of the rhizosphere (Nye, 1981; Galvalez & Clark, 1991), and the nutrient solution used in the experiment contained

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a mixture of NO_3^- and $NH4^+$. Other possible causes of pH decreases in the rhizosphere include root exudation of amino acids and organic acids (Richards, 1987), or root respiration that results in dissociation of H_2CO_3 to supply H^+ ions (Mengel & Kirkby, 1987).

Table 6.6 Mean pH of soil solute at 21 days after emergence

Treatment	**pH 4.0**	**pH 5.5**
1. Seed fortified with 250 µM $CaSO_4$	3.6	5.1
2. Seed fortified with 625 µM $CaSO_4$	3.7	5.2
3. Seed fortified with 1000 µM $CaSO_4$	3.7	5.1
4. Seed pelleted with 50 mg kg^{-1} $CaSO_4$	3.9	5.4
5. Seed pelleted with 50 mg kg^{-1} $CaCO_3$	3.9	5.4
6. Control	3.6	4.8
Mean	**26.4**	**36.5**
LSD $_{(0.05)}$ pH	**0.051**	**0.061**
Ca-source	**0.074**	**0.097**
pH x Ca-source	**0.102**	**0.135**

EXPERIMENT 3

Seedling survival under field conditions was similar to that observed under controlled environments. The number of seedlings surviving in the control treatment gradually declined starting from 7 days after emergence (Table 6.7). For cultivar Falcon 82% of the original number of seedlings from the untreated seeds survived 21 days after emergence, whereas for cultivar Kwarts, the number of seedlings surviving in the control treatment declined from 90% at 7 days after emergence to 77% at 21 days after emergence. Overall, the decline in survival rates was of a lesser magnitude compared to the growth chamber experiments. Treating the seed with Ca significantly improved seedling survival of both cultivars, and pelleting resulted in the highest numbers of surviving seedlings. Increasing the Ca concentration from 1000 to 2500 µM in the gypsum priming treatment did not result in better seedling survival. Priming the seeds with 1000 µM Ca as either $Ca(NO_3)_2$ or calcimax achieved similar seedling survival as priming with 2500 µM gypsum. Overall, pelleting or priming the seed resulted in better seedling survival, and lime had the highest survival rates in both cultivars.

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Table 6.7 Effect of seed treatment on groundnut seedling survival in the field

Treatment	Seedling survival (%) at 7, 14 and 21 days after emergence (DAE)					
	cultivar ***Falcon***			cultivar ***Kwarts***		
	7 DAE	**14 DAE**	**21 DAE**	**7 DAE**	**14 DAE**	**21 DAE**
Priming						
G-1000 µM	92	92	90	91	91	88
G-2500 µM	96	93	92	93	92	85
C/max-1000 µM	96	93	92	91	88	84
$CaNO_3$ –1000 µM	93	93	92	90	88	84
Pelleting						
Gypsum	97	93	91	96	92	90
Lime	99	97	97	99	95	92
Control	90	88	82	83	81	77
Mean	**95**	**93**	**91**	**92**	**90**	**86**
LSD $_{(0.05)}$	**6.56**	**5.55**	**6.70**	**5.13**	**6.15**	**7.62**

For cultivar Falcon all the vegetative growth parameters increased significantly when the seed was pelleted or primed (Table 6.8). Plants in the control treatments produced the least number of leaves per plant (10), had the least total leaf area per plant (91.4 cm^2) and the least shoot dry mass (0.84 g $plant^{-1}$). Priming or pelleting increased the number of leaves by up to 120%, leaf area by up to 179%, and shoot dry mass by up to 282%. Similar increases in the growth parameters were observed for cultivar Kwarts (Table 6.9).

For both cultivars, plants in the lime treatment bore more leaves per plant, had the highest leaf area and shoot dry mass compared to plants in the rest of the treatments. Priming the seed with gypsum at 2500 µM Ca did not have an advantage over priming with 1000 µM Ca for all the growth parameters. Overall, pelleting seed with lime or gypsum at planting gave better results than priming the seed. For both cultivars performance of seeds primed with gypsum was more enhanced than that of seeds primed with either calcimax or $Ca(NO_3)_2$.

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Table 6.8 Effect of seed treatment on vegetative parameters of *Falcon* at 28 days after emergence

Treatment	Plant height (cm)	No. of leaves per plant	Total leaf area per plant cm^2)	Shoot dry mass (g $plant^{-1}$)
Priming				
G-1000 µM	12.6	18	175.6	2.44
G-2500 µM	11.5	18	181.4	2.21
C/max-1000 µM	11	13	123.6	1.95
$CaNO_3$ -1000 µM	10.9	12	132.7	2.17
Pelleting				
Gypsum	12.6	16	186.0	2.04
Lime	13.4	22	255.5	3.21
Control	9.8	10	91.4	0.84
Mean	**11.7**	**16**	**163.8**	**2.12**
LSD $_{(0.05)}$	**1.295**	**2.804**	**28.890**	**0.490**

Table 6.9 Effect of Ca-treatment on vegetative parameters of *Kwarts* assessed at 42 days after planting

Treatment	Plant height (cm)	No. of leaves per plant	Total leaf area per plant (cm^2)	Shoot dry mass (g $plant^{-1}$)
Priming				
G-1000 µM	15	23	323.0	3.11
G-2500 µM	13.6	22	233.0	2.68
C/max-1000 µM	12.8	22	234.9	2.13
$CaNO_3$ -1000 µM	12.5	22	255.8	2.79
Pelleting				
Gypsum	13.6	23	397.0	4.41
Lime	17.9	32	634.6	6.00
Control	11.3	16	156.1	1.69
Mean	**13.8**	**23**	**319.2**	**3.26**
LSD $_{(0.05)}$	**2.169**	**4.031**	**58.758**	**1.120**

Similar results on improved plant growth in acid soils due to lime pelleting have been observed (Loneragan & Dowling, 1958; Deinum & Eleveld, 1986; Pijnenborg & Lie, 1990). Loneragan & Dowling (1958) observed better growth of *Trifolium subterraneum* L. after coating the seeds with lime to counteract acidity. Deinum & Eleveld (1986) reported that lucerne seeds pelleted

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with 30 kg ha^{-1} $CaCO_3$ nodulated significantly better and produced almost similar dry mass to seeds grown in soils limed with 1000 kg ha^{-1} $CaCO_3$. Pijnenborg & Lie (1991) observed better seedling establishment and nodulation of lucerne (*Medicago sativa* L.) due to lime-pelleting, and this resulted in improved nitrogen yield.

6.4 CONCLUSIONS

The results demonstrate that priming or pelleting groundnut seed with Ca improved seedling survival and the vegetative growth of the plant at low pH. The most effective source of Ca for pelleting groundnut seeds was $CaCO_3$, while $CaSO_4$ was the most efficient source of Ca for seed priming. Coating or priming seeds with small amounts of these Ca sources appeared to provide sufficient Ca to enable groundnut seeds to establish well in acid soils. Thus, efforts to optimise conditions for better seedling establishment in acid soils by providing "starter" Ca to the seed should be further investigated for consideration in situations where adequate lime cannot be applied. Experiments to establish whether the enhanced growth observed during the early vegetative stages will be reflected in improved yields should be initiated on the acid sandy soils in the smallholder sector of Zimbabwe.