

Determination of Optimum on-farm Seed Priming Time for Maize (*Zea mays* L.) and Sorghum (*Sorghum bicolor* [L.] Moench) for use to Improve Stand Establishment in Semi-arid Agriculture.

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Abstract

Observations and surveys in semi-arid smallholder agriculture in Zimbabwe suggest that stand establishment of many crops is often extremely poor and is the major cause of low yields. 'On-farm' seed priming experiments were conducted in pots to identify the optimum priming time and compare rate of emergence and early growth of primed and nonprimed seed. Soil mixed with sand in a 1:1 ratio was filled into pots. Pots were watered to field capacity on the evening prior to sowing and left overnight. Seed of maize (cv. R201 and PAN6363) and sorghum (cv. Red Swazi and Muchayeni) was soaked in water for 0, 8, 10, 12, 14, 16, 18, 20, 22 and 24 hours. Soaking time was staggered so that all soaking durations terminated at the same time. At the end of priming time seed was removed from water, surface dried and samples of 10 and 24 maize and sorghum seeds, respectively, were sown into each pot. Seedling emergence was assessed on all priming durations in maize and on 0, 8 and 10 h in sorghum because over 50% sprouted before sowing in longer priming times. Early seedling growth was assessed at 14 days after sowing using three seedlings from each treatment. This study provided 'safe limits', that is, the maximum length of time for which maize 24 h and sorghum seed 10 h should be primed, which if exceeded could lead to seed or seedling damage. These were up to 24 h for maize varieties and 10 h for sorghum varieties. Soaking seed of sorghum varieties for 12 h or more caused pre-sowing germination, suggesting that the seed could be susceptible to damage during sowing operations. Time taken for 50% of the seed sown to emerge decreased as priming durations increased from 0 to 10 h in sorghum and 0 to 24 h in maize and was reduced by 20 and 23% by soaking for 24 h and 10 h in maize and sorghum, respectively. Both emergence and early growth at 14 days after sowing were improved by soaking. This response of sorghum and maize seed to on-farm priming is an important development which can be used to improve crop stand establishment and early growth in semi-arid agriculture.

Key words: semi-arid; crop establishment; sorghum; maize; on-farm seed priming; Zimbabwe.

Introduction

Obtaining suitable crop stand establishment and thus high yield in semi-arid agriculture are some of the critical management problems af-

fecting rainfed-farming families in semi-arid areas. Observations and surveys in the farmers' fields in semi-arid smallholder agriculture in Zimbabwe suggest that stand establishment in many crops is often extremely poor and a major

cause of low yields (Chiduzo, 1987; 1993; Chivasa *et al.* 1998). Poor stands and the frequent need to re-sow have been reported in many semi-arid areas, with consequently increased labour costs and exhaustion of seed (Chiduzo, 1987; 1993; Chiduzo *et al.* 1995; Oosterhout van, 1996). Harris (1996) showed that conditions after sowing had a large influence on emergence and seedling vigour in sorghum and argued that speed of germination and emergence was an important determinant of successful establishment. High and rapid germination and emergence determine good stand establishment, and related vigorous early growth of seedlings often produces higher yields (Witcombe and Harris, 1997). Rapidly germinating seedlings could emerge and produce extensive root systems before the upper layers of the soil dried out.

Reasons for poor stand establishment in tropical crops have been documented elsewhere (e.g. van Oosterom *et al.* 1996; Harris, 1996; Chivasa *et al.* 1998). These constraints on stand establishment can be addressed but at a cost that may not be afforded by smallholder farmers (Harris, 1992). Harris (1996) proposed a low cost and low risk intervention termed 'on-farm' seed priming for all categories of farmers. Essentially, on-farm seed priming entails hydration of seed to a point where germination processes begin but radicle emergence does not occur before seed is planted in the soil. Any adverse effects of rapid dehydration are more than offset by the benefits of faster emergence and vigorous seedling growth (Harris *et al.* 1999). This approach is termed on-farm seed priming to distinguish it from the energy-intensive, high technology seed priming, seed hardening or seed conditioning process used in high input temperate agriculture and horticulture (Parera and Cantliffe, 1994).

The use of the latter technique has been well documented by a number of authors (Taylor *et al.* 1988; Paul and Chaudhury, 1991; Parera and Cantliffe, 1994). The methods used in temperate situations, include use of solid matrix materials (Taylor *et al.* 1988), a variety of osmotically active compounds (Brocklehurst *et al.* 1984) and organic salts (Paul and Chaudhury, 1991). It involves controlled hydration that induces various enzyme systems, the benefits of which are maintained after seeds are dried to their original water content and stored. Germination is faster, more

uniform and is often increased (Parera and Cantliffe, 1994). All these are very important under cool, damp conditions prevalent in temperate areas. In contrast, tropical crops are often sown under hot and dry conditions using unsophisticated planting techniques. Under these conditions, low temperatures do not limit seeds but imbibition can be slow. 'On-farm' seed priming begins hydration of the seed by soaking in water, usually overnight, before it encounters the harsh environment of the soil.

Research on improving crop establishment has been largely carried out in temperate regions focusing on horticultural crops. For tropical crops under semi-arid conditions, Harris (1996) in Botswana (sorghum) and Harris *et al.* (1999) in India (maize, upland rice, chickpea and wheat) reported faster emergence, good stand, faster growth and higher yield after seed priming. In Zimbabwe, no such research has been conducted, although some farmers in Musikavanhu communal area have indicated that they sometimes soak maize seed for various periods of time prior to sowing (Chivasa *et al.* 1998). Current farming practice provides a point of departure for developing and refining technologies to address poor crop stand establishment. There is need to understand the 'safe limits' of priming crop varieties grown in semi-arid environments. The objective of this study was to identify optimum on-farm seed priming duration(s) for maize and sorghum, the major crops grown in the Musikavanhu Communal Area of Zimbabwe.

Materials and Methods

Pot experiments were conducted at Save Valley Experiment Station in the south east of Zimbabwe, altitude 444 m above sea level, latitude 20° 21' S and longitude 32° 23' E. The experiment was conducted using a medium-grained sand loam derived from granite alluvium collected from a depth of 0 to 15 cm. The soil is classified in the US Taxonomy as a Eutic Eutochrept, under the FAO system as a Chromic Cambisol and the Zimbabwe series name is Sabi 4U.1. The soil was mixed with sand in a sand : soil ratio of 1:1 to improve friability of the soil to avoid compaction and severe crusting

after sowing. Seven kilograms of the mixture was placed into each 5 litre asbestos pot. Pots were watered to field capacity on the evening prior to planting and left overnight.

Maize seed (cvs R201 and PAN6363 - three-way hybrids of short maturity duration widely adapted for semi-arid areas) and sorghum seed (cvs Red Swazi and Muchayeni - open pollinated improved variety of short maturity duration and a landrace of long maturity duration, respectively) were soaked in water for 0, 8, 10, 12, 14, 16, 18, 20, 22 and 24 h at room temperature. Time of priming initiation was staggered so that all priming treatments terminated at the same time to enable planting to take place at the same time. At the end of the priming period, seeds were removed from the water and surface dried using tissue papers. Samples of 10 seeds of maize and 24 seeds of sorghum were sown by hand immediately after surface drying to a depth of 5 cm and 3 cm, respectively, into the asbestos pots.

There were three replicates for each soaking time \times variety combination for both maize and sorghum. A completely randomised design was used arranged as a factorial experiment with priming time and crop varieties as factors. Priming durations of twelve hours and above were discarded in sorghum because over 50 percent of the seed soaked for these durations sprouted prior to sowing. Therefore, only 0, 8 and 10 hours priming durations were tested for sorghum. Water was added to pots as necessary.

Seedling emergence was assessed twice daily, in the morning at 0600 hours and afternoon at 1400 hours up to 7 days after sowing (DAS) and, thereafter, once daily in the morning up to 14 DAS. Emergence data were used to calculate time in hours to 50 percent emergence. Rate of emergence was calculated as the reciprocal of the time taken for 50 percent of the seeds to emerge.

At 14 DAS, three seedlings from each pot were randomly sampled for early growth analysis. Plants were dug up using garden forks with as much of the root system as possible. Number of root axes greater than or equal to 1 cm, number of fully developed leaves and plant height to the insertion of fully expanded leaf were recorded. Root were removed and shoot samples were oven dried to constant weight to determine shoot dry weight.

The experiment was repeated twice and results pooled before analysis. Emergence percent, time to 50 percent emergence and early growth data were analysed using Genstat 5 statistical programme.

Results

Seedling emergence

Sorghum emergence

Soaking sorghum seed for 12 h or more caused over 50 percent sprouting before sowing suggesting that they would be susceptible to damage during sowing operations. Therefore, these treatments were discarded. Rate of sorghum seedling emergence was influenced significantly ($p < 0.001$) by priming duration. By 2 DAS sorghum seed primed for 8 and 10 h had more seedlings emerged than nonprimed seed (Figures 1a and b). There was delayed emergence in both sorghum varieties for nonprimed seed. Sorghum seedlings emergence from seed primed for 8 h differed significantly from nonprimed seed up to 5 DAS in Muchayeni. However, no such difference was significant between 8 h priming duration and nonprimed as from 6 up to 14 DAS in Muchayeni.

Ten hour priming duration had significantly higher emergence percent than 0 and 8 h in Muchayeni up to 14 DAS. However, there was no significant difference between 0 and 8 h priming durations from 8 up to 14 DAS in both varieties. Ten hour priming period performed consistently better than 0 and 8 h at all DAS except at 4 DAS where there was no significant difference between 8 h and 10 hour priming durations in both varieties (Figures. 1a and b). Final emergence percent at 14 DAS was significantly ($p < 0.05$) higher in seed primed for 10 h than seed primed for 0 and 8 h durations in Muchayeni. However, in Red Swazi, there was significant difference between 0 and 10 h but not between 8 and 10 h nor 0 and 8 h durations. The results of this study suggest that 10 h priming duration appears to be the optimum 'safe' soaking time for sorghum varieties tested in this experiment.

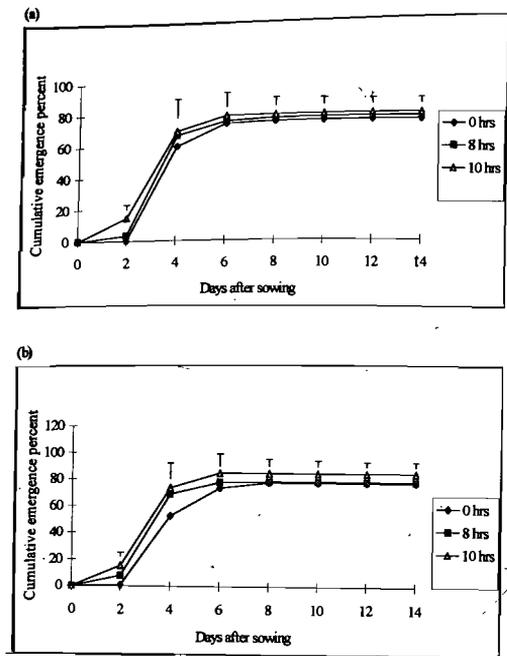


Figure 1: Mean cumulative emergence percent of sorghum varieties, Red Swazi (a) and Muchayeni (b) primed for different durations. Vertical bars represent LSD (0.001)

increased as priming duration increased from 0 to 10 h (Table 1).

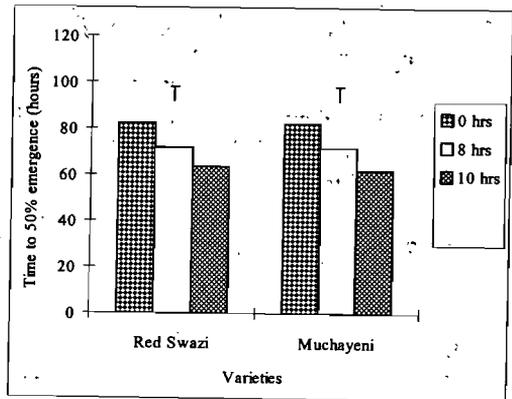


Figure 2: Time to 50 percent emergence of sorghum varieties primed for different durations. Vertical bars represent LSD (0.001)

Time to 50 percent emergence and rate of emergence

Figure 2 shows how the time required for 50 percent of the seeds sown to emerge decreased as priming duration increased. Time to 50 percent emergence was reduced by 23 percent in both Red Swazi and Muchayeni by soaking for 10 h. Rate to 50 percent emergence was significantly ($p < 0.001$)

Maize emergence

Seedling emergence percentages of maize varieties primed for different durations are shown in Figures 3a and b. For clarity, only 0, 12, 18 and 24 hours were plotted as graphs and the other priming durations are reported in the text. Maize seedlings emergence was influenced by priming duration and maize seed primed between 12 and 24 h had significantly ($p < 0.001$)

Table 1. Effect of on-farm seed priming at three different priming durations on some sorghum variables measured 14 DAS (except rate of emergence).

Variable	Priming duration (h)			Sig.	CV%	LSD
	0	8	10			
Red Swazi						
No. of leaves (plant ⁻¹)	2.43 ^a	3.33 ^b	3.93 ^c	***	8.4	0.35
Height (cm plant ⁻¹)	1.97 ^a	2.42 ^b	2.98 ^c	***	8.0	0.25
No. of root axes (plant ⁻¹)	1.72 ^a	2.00 ^a	2.73 ^b	***	11	0.29
Shoot dry weight (g)	0.05 ^a	0.06 ^b	0.08 ^c	***	10	0.008
Rate to 50% emergence (h ⁻¹)	0.29 ^a	0.34 ^b	0.38 ^c	***	6.6	0.03
Muchayeni						
No. of leaves (plant ⁻¹)	2.43 ^a	3.40 ^b	3.73 ^b	***	8.4	0.35
Height (cm plant ⁻¹)	2.00 ^a	2.30 ^b	3.05 ^c	***	8.0	0.25
No. of root axes (plant ⁻¹)	1.55 ^a	2.05 ^b	2.73 ^c	***	11	0.29
Shoot dry weight (g)	0.06 ^a	0.06 ^a	0.07 ^b	***	10	0.008
Rate to 50% emergence (h ⁻¹)	0.29 ^a	0.34 ^b	0.39 ^c	***	6.6	0.03

*** Significantly different at $p < 0.001$; C.V. = Coefficient of Variation; LSD = Least Significance Difference at $p < 0.001$.

Means followed by the same letter in a row are not significantly different.

higher number of seedlings emerged as from 2 up to 9 DAS than nonprimed maize seed. In both R201 and PAN6363, there was no significant difference between 12 and 18 h priming durations in terms of emergence percent at all times.

was no significant difference between 12 and 18 h these priming durations performed better than nonprimed seed up to 9 DAS indicating that priming seed of maize before sowing encouraged faster emergence while the soil is still moist. This is very important in semi-arid areas. There was little difference between 12 and 20 h of priming on emergence (data not shown). Maximum emergence percent in maize was obtained following 24 h priming, although there was no significant difference between maize seed primed for 24 h and nonprimed in terms of final emergence in both varieties. Time to 50 percent emergence and rate of emergence.

Increase in priming period significantly reduced time to 50 percent emergence and soaking maize seed for 24 h reduced time to 50 percent emergence by 20 percent in R201 and PAN6363 (Figure 4). Rate of emergence significantly ($p < 0.001$) increased with increase in priming period in both varieties (Table 2). Highest rate was obtained after 24 h priming period and the least in nonprimed seed in both maize varieties.

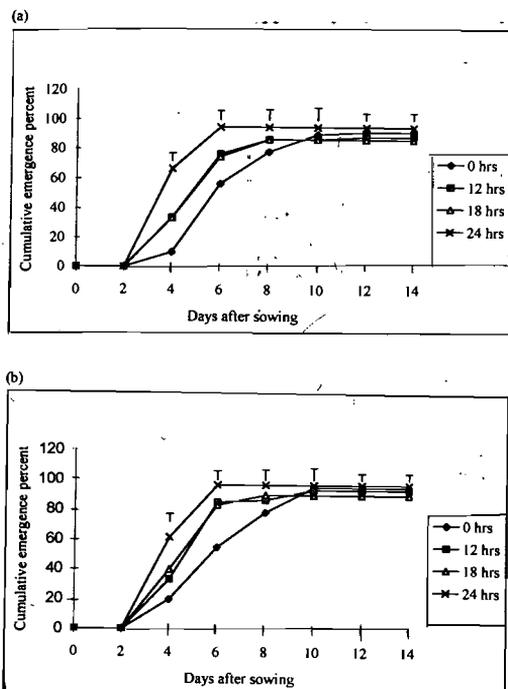


Figure 3: Mean cumulative emergence percent of maize varieties, R201 (a) and PAN 6363 (b) varieties primed for different durations. Vertical bars represent LSD (0.001).

Twenty-four hour priming duration had significantly more number of seedlings than all other priming durations up to 9 DAS. Although there

Seedling growth

Sorghum growth

The results of the overall analysis of variance concerning the effects of priming on all sorghum growth parameters measured 14 DAS are summarised in Table 1. Primed sorghum seed produced significantly ($p < 0.001$) seedlings with more leaves than non-primed. Ten hour priming duration had significantly ($p < 0.001$) the highest and nonprimed had the least number of leaves. Sorghum seedling height was significantly ($p < 0.001$) influenced by priming such that primed sorghum seed produced plants that grew faster and were taller than non-primed seed by 14 DAS. Primed sorghum seed produced seedlings with significantly ($p < 0.001$) more root axes than non-primed. Primed sorghum seed produced significantly ($p < 0.001$) heavier seedlings by 14 DAS than non-primed seed. Rate of emergence was related to subsequent crop growth as exhibited by highest number of leaves, root axes, tallest plants and highest shoot-dry weight following optimum priming period (10 h) in sorghum varieties. Seed that emerged fastest fol-

lowing priming grew more vigorously over 14 DAS.

Maize growth

Table 2 summarises the results of the overall analysis of variance concerning the effects of priming on all maize growth parameters measured at 14 DAS. Priming maize seed before sowing produced seedlings with significantly ($p < 0.001$) more leaves than non-primed. Number of leaves increased as priming durations increased from 0 to 24 hours. Primed maize seed produced plants

that significantly ($p < 0.001$) grew faster than non-primed seed by 14 DAS. Non-primed maize seed had the shortest plants by 14 DAS and the tallest plants were obtained following 24 hour priming. Maize seedlings with significantly ($p < 0.001$) more root axes were obtained from primed seed than non-primed seedlings. Increasing priming durations significantly ($p < 0.001$) increased maize shoot dry weight in both varieties. Maize seedlings that emerged earlier follow leaves, highest number of root axes, the tallest and the heaviest were obtained following 24 h priming period.

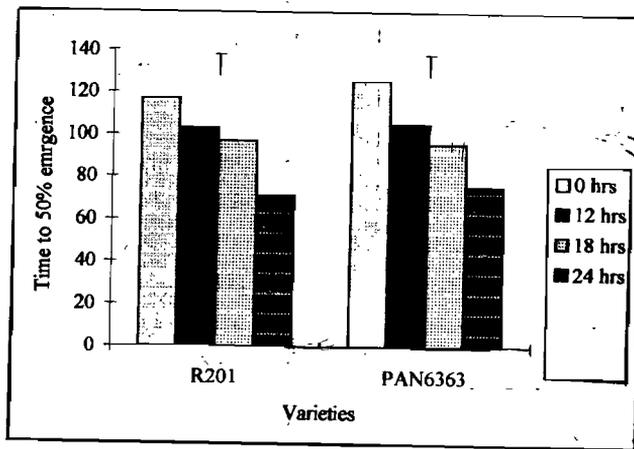


Figure 4: Time to 50 percent emergence of sorghum varieties primed for different durations.

Table 2: Effect of on-farm seed priming at ten different priming durations on sorghum variables measured 14 DAS (except rate emergence)

Variables	Priming duration (hours)										Sig.	LSD	CV
	0	8	10	12	14	16	18	20	22	24			
R201													
No. of leaves (plant ⁻¹)	2.2 ^a	2.9 ^b	3.5 ^c	3.7 ^c	3.7 ^c	3.6 ^c	3.6 ^c	4.2 ^d	4.1 ^d	4.2 ^d	***	0.4	9.9
Height (cm plant ⁻¹)	2.6 ^a	3.0 ^b	3.4 ^c	3.3b ^c	3.5 ^c	3.5 ^c	3.7 ^d	4.0 ^d	4.1 ^d	4.1 ^d	***	0.3	7.6
No. of root (plant ⁻¹)	6.1 ^a	6.3 ^a	7.6 ^b	8.2 ^b	7.7 ^b	7.9 ^b	7.6 ^b	9.2 ^c	9.0 ^c	9.2 ^c	***	0.8	8.8
Shoot dry weight (g)	0.22 ^a	0.27 ^b	0.3 ^c	0.4 ^d	0.39 ^d	0.39 ^d	0.40 ^d	0.43 ^e	0.42 ^e	0.54 ^f	***	0.1	12.9
Rate to of emergence	0.090 ^a	0.081 ^a	0.08 ^b	0.1 ^c	0.096 ^c	0.1 ^c	0.103 ^c	0.104 ^c	0.121 ^d	0.140 ^e	***	0.01	7.7
PAN6363													
No. of leaves (plant ⁻¹)	2.6 ^a	2.6 ^a	2.8 ^{ab}	3.2 ^{bc}	3.6 ^{cd}	3.8 ^d	3.9 ^d	3.8 ^d	4.1 ^e	4.2 ^e	***	0.4	9.9
Height (cm plant ⁻¹)	2.5 ^a	2.9 ^b	3.1 ^{bc}	3.2 ^{bc}	3.4 ^{cd}	3.7 ^d	3.7 ^d	3.7 ^d	4.2 ^e	4.3 ^e	***	0.3	7.6
No. of root (plant ⁻¹)	5.8 ^a	6.7 ^b	6.6b ^b	7.1 ^b	7.3 ^b	7.7 ^c	7.8 ^c	8.5 ^{cd}	8.9 ^d	9.1 ^d	***	0.8	8.8
Shoot dry weight (g)	0.186 ^a	0.284 ^b	0.37 ^c	0.3 ^d	0.35 ^{de}	0.384 ^e	0.397 ^e	0.403 ^e	0.428 ^{ef}	0.467 ^f	***	0.056	12.9
Rate to 50% emergence	0.08 ^a	0.08 ^a	0.08 ^a	0.1 ^b	0.1 ^b	0.099 ^b	0.104 ^b	0.105 ^b	0.129 ^c	0.132 ^c	***	0.009	7.7

*** Significantly different at P<0.001; C.V. = Coefficient of Variation; LSD = Least Significance Difference at p<0.001. Means followed by the same letter in a row are not significantly different.

Discussion

'On-farm' priming of sorghum and maize seed showed that emergence rate and final emergence could be increased considerably. The optimum priming period was up to 24 hours in maize and 10 hours in sorghum. Increased rate of emergence allows a higher percentage of seedlings to emerge before soil dries up and good crop stand establishment is possible. This may translate into increased grain yield. This response of sorghum and maize to on-farm seed priming is an important development in semi-arid agriculture and can be used in the field to improve crop emergence. Results of this study are in general agreement with Harris (1992; 1996), Witcombe and Harris (1997) and Harris *et al.* (1999) who found similar response in maize, rice and chickpea in India and sorghum in Botswana after priming these crops.

Absence of any significant difference between 0 h and 24 h priming durations obtained at final emergence in maize in this study suggest that nonprimed seed may finally achieve their final emergence potential, although after a protracted time. However, ideal conditions in semi-arid agriculture are rare and soil moisture is a major limiting factor when maize and sorghum are sown. In semi-arid conditions, soil moisture often decreases following sowing and salt concentration increases, affecting the water potential, reduced hydraulic conductivity and imbibition is impaired (Hadas, 1977; Brar *et al.* 1992). Under such conditions seed that emerge faster while the soil is still moist can produce complete stands and this is possible if seed is primed in water before planting.

Priming sorghum and maize seed increased rates of emergence and this is very important since rate of emergence determines the duration of exposure to high temperature, soil drying, risk of seed dehydration and attack by soil-borne pathogens (Mohamed *et al.* 1988; Harris, 1996). Reduction of time to 50 percent emergence following priming in this study is in general agreement with Rao *et al.* (1987), Hardigree (1994) and Harris (1996). Wanjura *et al.* (1969) reported that earliness and faster rate of emergence are important determinants of yield capabilities of annual crops.

In addition to faster emergence, rapid seedling development and establishment are very important (Steiner and Jacobson, 1992). Seedling growth

and development was faster as priming duration increased from 0 to 10 h for sorghum varieties and from 0 to 24 h for maize varieties. Measured at 14 DAS, plant height, shoot dry matter, number of leaves and number of root axes were all significantly greater from primed than nonprimed seed. In particular, rate of root production is critical in semi-arid environments where soil moisture after sowing often deteriorates rapidly to critical low levels. Quick development of roots following priming can mitigate against these adverse conditions. These indices of seedling vigour are associated with higher yields in many crops including maize resulting from earlier flowering, better tolerance to drought and early maturity, often around 10 days earlier (Harris *et al.* 1999).

Chivasa *et al.* (1998) reported that 37 percent of the farmers in Musikavanhu communal area in Zimbabwe indicated that they sometimes soak their maize seed prior to planting to 'catch up' when a sowing opportunity is missed, but there was poor information on priming duration. In the farmers' minds on-farm seed priming is a 'conditional' practice, applicable only under adverse circumstances. Farmers had not applied the technique under otherwise optimal sowing conditions. This study provides 'safe limits', that is, the maximum length of time for which farmers should prime seeds and which, if exceeded could lead to seed or seedling damage. These were 10 hours for sorghum and up to 24 hours for maize. Soaking sorghum for 12 hours and beyond was found detrimental in this study. The results of the survey by Chivasa *et al.* (1998) and the pot experiments reported in this paper showed that on-farm seed priming is a robust and practical technology that should be widely promoted for adoption to improve crop production in semi-arid agriculture.

While 24 hours priming in maize performed better in every aspect of crop emergence and early growth, practical applicability is important when considering recommendations for use by farmers. Any recommendations made to farmers have to be robust and compatible with their perception of time, that is, soaking time should not be so precise that farmers without timepieces or those who are unable to read time could not measure them, hence 12 hours or 'overnight' seems

to be ideal to cater for all farmers, irrespective of the farmers' educational background. In fact there was little difference in time to 50 percent emergence between 12 to 20 h priming duration.

The major clients for this on-farm seed priming technology are smallholder rainfed farmers whose scale of mechanisation is small. There are a number of practical problems with on-farm seed priming where the level of mechanisation is high. Seed soaking is directly relevant to hand-sown seed and since soaked seed swells up, planting rates and efficiency of delivery will change when mechanical planters are used (Harris, 1996). However, in simple planters it may be just a matter of changing the size of the controlling aperture, but in planters supplied with standard plates or discs more complicated modifications may be necessary to achieve comparable sowing rates (Harris, 1996). Furthermore, relatively soft pre-soaked seed might be more susceptible to physical damage in planters which use 'knockers' to eject seed.

This study demonstrates clearly that 'on-farm' seed priming is a practical way for farmers in semi-arid areas to maximise emergence and early vigour of maize and sorghum, traits that have been linked repeatedly to improved crop performance (Harris *et al.* 1999). Results obtained in this study may have significant agronomic implications for establishment of sorghum and maize in the field in semi-arid rainfed farming systems where stand establishment is a major constraint on crop production. Rapid seedling emergence and production of deep root systems before the upper layer of the soil dries out will improve crop stand establishment and early growth. Work is going on in on-station and on-farm trials in Zimbabwe to test whether: enhanced growth following priming leads to higher yield; primed seed are easier to sow; a delay in sowing following priming is detrimental to seed viability; and to assess stand establishment of primed seed under different rainfall regimes.

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