FINAL TECHNICAL REPORT

R7440 Seed priming in tropical crops

Executive Summary

The overall aim of the project was to test the crop physiology underpinning 'on-farm seed priming', a technology previously promoted by DFID. It was established that previously-reported benefits of priming in the field could be demonstrated in controlled environments for maize, rice and wheat. In experiments in the laboratory, controlled environments and in the field, there was no evidence that priming inherently changed the way that plants grow. Instead, the benefits depend on the extent to which priming can advance germination and emergence. This in turn depends on the soil physical conditions at sowing. In maize, priming benefits in controlled environments were greater in drier conditions, but there was an adverse effect in conditions of excessive moisture at high planting temperatures. However, in the field this was rarely a problem, even with a combination of rainfall and high temperatures, presumably due to sufficient drainage through the soil. In on-station trials at Save Valley, Zimbabwe, there were adverse effects of priming on final emergence or time to 50% emergence in maize in only 4 out of 34 planting environments tested. In participatory trials with farmers (joint with project R7189, Cultivar competitiveness and interactions with on-farm seed priming for integrated weed management), the faster emergence from primed seed was recognised and appreciated as primed crops were considered to be more competitive against weeds. These outputs provide assurance to the development community that priming is a scientifically-sound practice that can improve yields through increased crop stand, more rapid seedling emergence and increased uniformity of the stand.

Background

In the semi-arid tropics, crops often fail to establish quickly and uniformly, leading to decreased yields because of low plant populations. Constraints to good establishment include poor seedbed preparation, low quality seed, untimely sowing, combined with adverse weather conditions after sowing. Participatory approaches show that farmers are aware of the problem of poor establishment. However, they often lack the means to optimise seedbed conditions before sowing and they are particularly at risk from adverse weather after sowing. On the other hand, good establishment increases competitiveness against weeds, increases tolerance to dry spells, maximises yields and avoids the costly and time-consuming need for re-sowing. Good establishment can also 'unlock' further benefits as farmers can consider inputs (such as fertiliser) that would not be worthwhile if establishment was poor.

Previous DFID-funded research (Harris, 1996; Harris *et al.*, 1999) showed that 'on-farm' seed priming leads to better establishment in tropical crops such as maize, sorghum, rice and chickpea. 'On-farm' seed priming involves simply soaking the seed in water overnight, surface drying and sowing the same day. Participatory approaches have led to rapid acceptance of the technique in areas of India and Zimbabwe as the technique gives clear benefit for little risk. As well as improved crop establishment, priming led to crops growing faster, flowering earlier and yielding higher. However, the physiological processes leading to these benefits were not well understood. In particular, the benefits later in the growth of the crop are much greater than might be expected from emergence 1-3 days earlier.

The above research suggested that some of the benefits of ‘on-farm’ seed priming can be gained in non-primed seed by seedbed preparation and sowing methods that give better seed-soil contact. This indicated that a large part of the benefit of ‘on-farm’ seed priming results simply from fast hydration of the seed, giving the primed seedlings an advantage in deteriorating seedbeds. It appeared that seedlings that germinated and grew rapidly were able to produce sufficiently deep root systems before the seed bed dried out, hardened or became too hot. However, these suggestions had not been tested experimentally. In consultation with overseas partners, the DFID Plant Sciences Research Programme identified a need to understand and quantify the physiological mechanisms that produce the benefits of ‘on-farm’ seed priming. It was assumed that, for the full benefits of seed priming to be realised, the development community must be convinced that the technology is both robust and based on sound scientific understanding.

Project Purpose

Methods to optimise cropping systems by agronomic means developed and tested.

(The Project Purpose is a specified output of the Plant Sciences Research Programme.)

Research Activities

1. To lead to output *‘Effects of ‘on-farm’ seed priming observed in maize and at least one other crop in controlled environments’*:

1.1 Identify field conditions in order to reproduce them in controlled environments

A ‘standard’ controlled environment of 30 °C (day) and 20 °C (night), with a 14 h daylength was chosen. Seeds were primed at 20 °C. However, as the effect of priming may be temperature-dependent, different temperature regimes were tested in the activities for output 2.

1.2 Field conditions reproduced in controlled environments to observe the effects of ‘on-farm’ seed priming in maize, cowpea and cotton

Priming effects were tested in maize, wheat, rice, chickpea and cotton. These experiments used 55-cm long tubes of sand as the growth medium. The sand was well-watered with nutrient solution at the start of the experiment, which gave moist but well-drained conditions at seed depth. Cowpea was not tested in growth experiments as preliminary tests of the effect of priming on germination in Petri dishes showed that priming decreased germination from about 90% to 40%.

2. To lead to output *‘Physiological basis of priming-related benefits in relation to seedbed physical conditions and soil nutrient dynamics quantified and understood’*:

2.1 Study effects of 'on-farm' priming on germination characteristics, and early seedling growth

The responses of maize cv. SC403 and wheat cv. Nduna to priming were studied in detail. This included dealing with the effect of temperature and the test environment.
Early seedling growth was studied in maize cv. SC501. As well as non-primed and primed seeds, three additional treatments of priming and drying-back, pre-humidifying then priming, and pre-humidifying and drying were tested. These seed treatments were tested on normal and artificially-aged seed. Seedlings were then allowed to grow at 15 °C and at 30 °C (with and without water stress, −0.75 MPa) on sloping filter boards.

2.2 Study whether benefits of priming result from allowing the seed to imbibe water rapidly, leading to earlier germination and emergence, model results

2.3 Effect of priming on pre-emergence shoot and root growth measured

Both these areas were addressed with experiments carried out in well-watered sand cores that were allowed to drain and dry for 9 days. The cores were planted with primed and non-primed maize seeds (SC403). The weights of individual seeds were monitored to assess imbibition, and destructive harvests were carried out leading up to emergence to follow root and shoot growth.

2.4 Investigate effects of priming on post-emergence growth, including relative growth rate, rooting depth and water uptake. Compare with findings on-station

Controlled environment experiments were carried out, based on the sand core system described in 1.2. As well as the well-watered treatment described there, additional treatments where the cores were allowed to drain and dry for 5 days and 9 days were tested. Different temperature regimes were tested, as described with the outputs.

On-station trials were carried out at Save Valley Experiment Station in the 1999/2000 and 2000/2001 seasons, with an additional trial in the 2001 dry season under irrigation. In one set of trials (Appendix 2), the interaction of priming with tillage practices and simulated planting rainfall was studied for maize and cotton. In another set of trials, daily sequential plantings of primed and non-primed maize were carried out to sample different planting environments and to compare the growth of plants that emerged on the same day from primed and non-primed seed (Appendix 3).

3. To lead to output *'Recommendation domains (climatic, environmental, socio-economic) for 'on-farm' seed priming clarified using participatory evaluation'*:

3.1 Identify an envelope of seedbed conditions where seed priming should be beneficial

Results from all aspects of this project were collated and discussed at project meetings.

3.2 A system of participatory evaluation will be carried out to show how priming benefits interact with different conditions of crop establishment used by well, average and poorly-resourced farmers in different natural regions of Zimbabwe

On-farm studies were conducted in Small Scale Commercial and Communal farming areas in Masvingo Province, Zimbabwe in 1999-00 and 2000-01 to allow farmers to assess the value of priming for themselves in paired plots. Farmers managed the trials using their usual management practices but yields were recorded by project staff. Discussions were held in each community during the season to assess farmers' perceptions of the strengths and weaknesses of priming. A questionnaire survey was also undertaken of 50 households prior to maize harvest to establish the seed soaking methods, if any, already used and views on the trials. These activities were carried out jointly with staff working on project R7189 (Cultivar competitiveness and interactions with on-farm seed priming for integrated weed management) so that results informed both projects.

Outputs

1. Effects of 'on-farm' seed priming observed in maize and at least one other crop in controlled environments.

Primed seeds generally gave faster seedling emergence than non-primed seeds planted at the same time, while there was little effect on final emergence (Table 1). However, priming cotton decreased final emergence and delayed emergence. Early-planted controls gave a similar or even greater benefit than priming, which suggests that priming works by advancing germination and emergence. This was tested in detail during the activities for output 2.

2. Physiological basis of priming-related benefits in relation to seedbed physical conditions and soil nutrient dynamics quantified and understood.

2.1 Germination characteristics

When germination of maize SC403 was tested between moist filter paper in Petri dishes at 30 / 20 °C, priming between 4 and 24 h did not lead to faster germination. Indeed, when thermal time during soaking was included, primed seeds took increasingly more thermal time to germinate the longer they were soaked. Seeds that were soaked for 17 h and then allowed to dry-back for 1 h germinated much faster than untreated seeds set in Petri dishes at the same time. The implications of this for growth of maize was tested in further controlled-environment experiments (see outputs 2.4 post-emergence growth).

There were no discernible effects of priming temperature, light/dark, or ratio of seed to water during priming on subsequent germination in Petri dishes. However, there was a large effect of temperature during germination tests on the effect of priming in maize (Fig. 1). Priming decreased the temperature optimum for rate of germination so that priming increased sensitivity to heat stress. The germination characteristics of maize in relation to priming are reported in more detail in Appendix 4. Of particular note is that the adverse effect of priming at high temperatures seemed to depend on hypoxia in certain test environments with excessive moisture.

Table 1. The effect of priming on emergence of seedlings from five crop species. 'Early-planted controls' were sown when primed seeds were placed in water to soak, 'controls' were planted at the same time as primed seeds. Time to 50% emergence (t_{50}) is based on time zero at start of soaking. The temperature regime was 30 °C (day)/ 20 °C (night).

Species	Priming time (h)	Treatment	Emergence	
			Final (%)	t_{50} (d)
Maize cv. SC403	17	Early-planted control	100	3.8
		Control	100	4.6
		Primed	96	3.8
Wheat cv. Nduna	17	Early-planted control	92	4.8
		Control	97	5.6
		Primed	94	4.6
Chickpea	8	Early-planted control	75	5.2
		Control	63	6.0
		Primed	67	5.8
Rice cv. IR36	17	Early-planted control	96	6.2
		Control	88	7.5
		Primed	79	6.6
Cotton	17	Control	83	115
		Primed	72	137

In contrast to maize, the adverse effect of priming at high test temperatures was not seen in wheat (Fig. 1) or chickpea (not shown). In wheat and chickpea, priming increased the rate of germination in Petri dishes. In wheat, this increase was smaller when an 8 h soak was used instead of a 17 h soak, even though imbibition was essentially complete after 8 h.

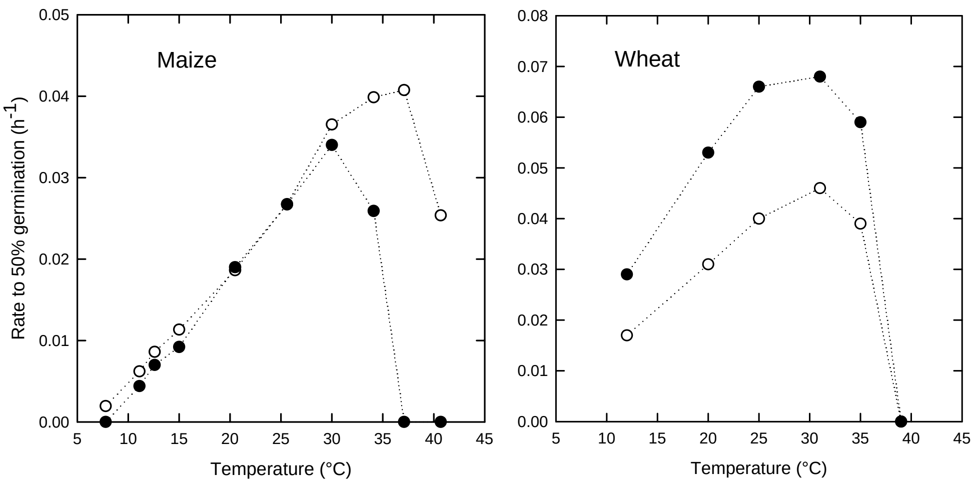

Fig. 1. Rate of germination in Petri dishes of primed (●) and non-primed (○) maize cv. SC403 and wheat cv. Nduna as a function of germination test temperature. Seeds were primed for 17 h at 20 °C.

2.1 Early seedling growth

Priming did not alter the elongation rates of root or shoots on sloping filter boards, nor was there any interaction with ageing or water stress. This suggests that priming does not help aged maize seed to 'self-repair'.

2.2 & 2.3 Imbibition and pre-emergence growth

By 24 h after planting in well-drained cores of sand at 35 / 28 °C, primed maize seeds had germinated (Fig. 2B) and downward root growth had started (Fig. 2C). At this stage, the fresh weight had not increased from that at planting (Fig. 2A). Thus primed seeds contain enough water to germinate and do not need to take up water from the soil to germinate. Instead the role of soil moisture is to prevent the seeds from drying-out. Non-primed seeds took over 24 h to reach the same fresh weight that primed seeds had at planting. When they reached this weight, they germinated and downward root growth started. Upward growth of the shoots towards the surface started about 24 h after the germination for both treatments. These experiments clearly show that priming benefits can result from rapid imbibition, leading to an advancement of germination and emergence.

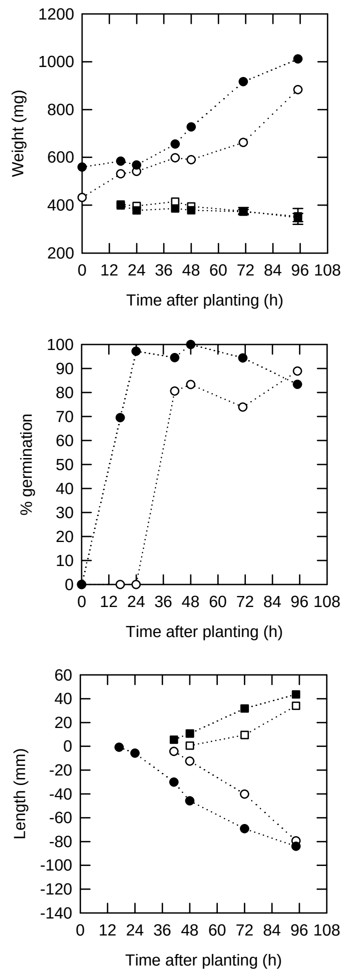

Fig. 2. Effect of priming for 17 h on fresh and dry weight (upper panel), germination (middle panel) and pre-emergence growth (lower panel) at 30 °C (day)/ 20 °C (night). Closed symbols primed, open symbols non-primed.

In laboratory experiments with soil from Save Valley Experiment Station (in Zimbabwe), priming for 12 h improved emergence and early growth in maize SC401 and cotton cv. SZ93-14. This was only monitored at one time period (8 d after sowing) but was tested for a range of aggregate sizes and soil matric potentials. These results are shown in more detail in Appendix 1.

2.4 Investigate effects of priming on post-emergence growth, including relative growth rate, rooting depth, compare with findings on-station

When the effect of priming on growth was tested under the same conditions used to test the effect on emergence (Table 1), there was little effect of priming on the growth of maize. Early-planting of non-primed seed gave better results than priming, and this effect was more marked if daytime temperatures of 35 and especially 40 °C were used. These results are reported in detail in Appendix 4. However, if primed and non-primed seeds were planted into cores of sand that were allowed to drain for an extra 8 days at 35 / 28 °C, then large benefits of priming on growth were apparent. These need to be interpreted in relation to the effect of priming on emergence under these conditions. At this temperature regime, there was an adverse effect of priming on final emergence for the first planting into well-watered sand cores (Fig. 3). For a second planting 4 days later, this adverse effect was lost and there was also an advancement of the emergence curve. For the final planting, there was an even greater advancement of emergence. At harvest 14 days after each planting, this meant that there was an adverse effect of priming on growth after the first planting, a neutral effect after the second planting, and a beneficial effect after the third planting (Table 2).

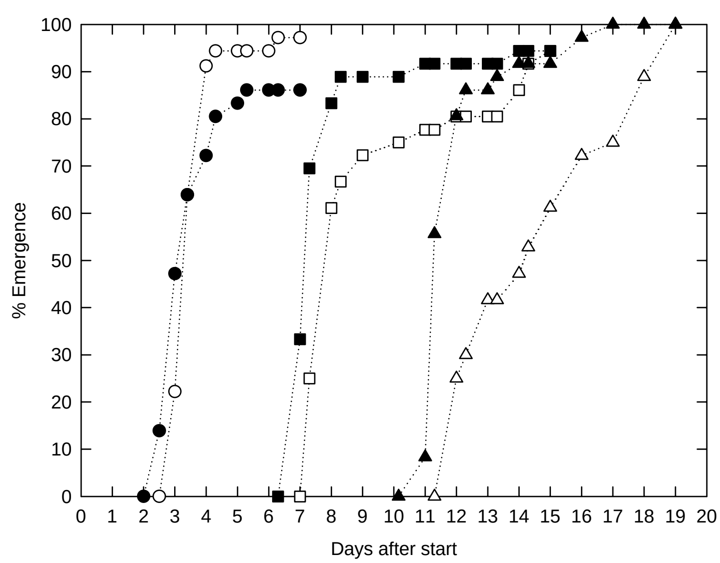

Fig. 3. Emergence of maize SC403 from sand cores allowed to drain for 1 day (circles), 5 days (squares) or 9 days (triangles) before planting of primed (closed symbols) or non-primed (open symbols) seed.

The data for individual plants from the third planting were plotted against day of emergence (Fig. 4). It can be seen that the earlier-emerging plants were bigger at harvest than the later-emerging plants, as would be expected. Both primed and non-primed plants followed the same relationship, showing that priming benefits resulted from advancement of emergence. There was no evidence that priming directly altered the growth rate. Together with the data from Fig. 2, this shows that priming benefits can be traced from rapid germination of imbibed seed leading to more rapid germination, and therefore an advancement of emergence and growth.

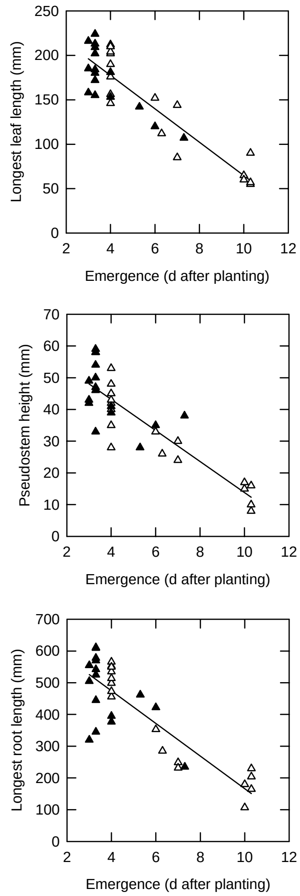

Fig. 4. Growth measurements of individual plants from third sowing (in Fig. 3 and Table 2) plotted against day of emergence. Closed symbols indicate primed plants.

Table 2. Effect of priming on three sowing occasions on growth of maize SC403 at 35 / 28 °C.

Variate(mm)		Sowing occasion (days after start)		
		1 (0)	2 (4)	3 (8)
Length of longest leaf	(non-primed)	238	197	140
	(primed)	217	190	175
Pseudo-stem height	(non-primed)	58	49	31
	(primed)	51	49	46
Longest root length	(non-primed)	569	473	371
	(primed)	547	482	477

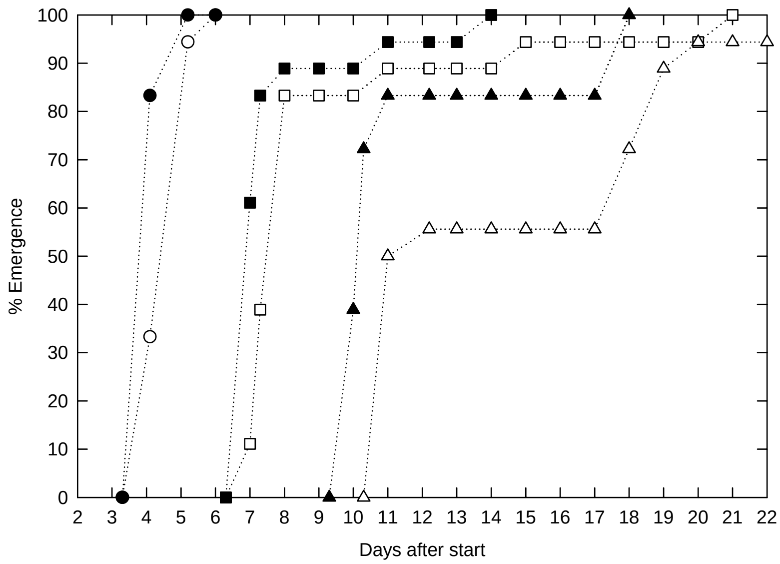

Fig. 5. Emergence of wheat cv. Nduna from sand cores allowed to drain for 1 day (circles), 5 days (squares) or 9 days (triangles) before planting of primed (closed symbols) or non-primed (open symbols) seed.

Experiments were carried out to determine the effect of drying-back on the effect of priming, both for planting into well-watered (conditions as for sowing 1 above) and drier conditions (as for sowing 3 above). For both emergence and growth, extended drying-back for 4 h decreased the adverse effects of priming on growth and emergence at 35 / 28 °C but removed the benefit of priming for drier conditions (see p. 13 of Appendix 4 for more details).

Similar experiments were carried out in wheat at 30/20 °C. The effect of priming on emergence was greater in drier cores (Fig. 5), as was the effect on growth (Table 3). The priming treatment used for wheat was 8 h, as preliminary experiments showed that a 17 h soak led to slower growth, despite the apparently greater benefit that this longer soaking time gave in Petri dish germination tests. As with maize, larger plants resulted simply from earlier emergence.

The implications of priming for nutrient acquisition were tested in controlled environments with nutrient status that varied with depth. Low nutrient controls used sand cores as before, but watered with water only. High nutrient controls used soil throughout, except for a layer of sand on the surface to give all plants the same establishment conditions. A split nutrient treatment used soil below 30 cm depth, with a layer of sand watered with water above this. The interaction of these treatments with simulated priming was tested. As the actual effect of priming depends on moisture, which would be affected by the depth of soil beneath the sand, priming was simulated by planting non-primed seeds 3 days apart. Plant growth measurements were made 21 and 24 days after the second planting. By this stage, plants in treatments containing soil were greener than those in sand only, and were growing better. However, growth measurements showed that there did not appear to be any interaction with simulated priming (not shown). At the time of writing this report (February 2004), the plants are being grown to grain harvest on residual moisture in order to simulate how smallholder farmers often grow wheat.

Table 3. Effect of priming on three sowing occasions on growth of wheat cv. Nduna at 30 / 20 °C.

Variate(mm)		Sowing occasion (days after start)		
		1 (0)	2 (4)	3 (8)
Length of longest leaf	(non-primed)	204	194	156
	(primed)	196	191	181
Pseudo-stem height	(non-primed)	52	48	36
	(primed)	57	52	49
Longest root length	(non-primed)	451	422	360
	(primed)	487	444	403

On-station trials are described in detail in Appendices 2 & 3. In maize, there was normally a beneficial effect of priming on the rate of emergence. The experiments reported in Appendix 2 represent 18 different planting environments, only two of which led to an adverse effect of priming on final emergence. In Appendix 3, only 2 out of 16 planting environments led to an adverse effect of priming. It should be noted that this is despite recorded temperatures in the seedbed being high enough to lead to priming decreasing the rate and extent of germination in some of the laboratory environments. It appears that this is much less of a problem in the field. In the experiments reported in Appendix 3, we were able to relate differences in the effect of priming between sowing occasions to soil physical conditions. On the one hand, for one sowing priming advanced time to 50% emergence by 3 days, which was related to crust formation following rainfall after sowing. As the soil crusted, the advancement from priming enabled most shoots to emerge before the soil became too strong, whereas the non-primed shoots became impeded below an increasingly strong layer. On the other hand, for sowings a few days later, the non-primed seedlings were at an advantage as they did not have time to reach the crust until it became softened by rainfall.

In experiments carried out under irrigation in the dry season in 2001, primed plants appeared to be growing faster as dry matter was greater for primed plants throughout the season (Fig. 7 in Appendix 2). However, the slope of the logarithm of weight against time was the same for both treatments. This shows that priming did not alter the relative growth rate, but rather advanced the growth curve. For the sowings in which the beneficial effect of priming on the timing of emergence was much less, there was little effect of priming on dry matter accumulation. These findings are consistent with those from controlled environments that show that priming benefits derive from advancement of emergence.

There was a consistent adverse effect of priming on final emergence and sometimes yield of cotton in the field (Appendix 2), which agrees with the germination data shown here in Table 1. However, this is not consistent with the results of laboratory experiments in Appendix 1, although this may reflect differences in seed quality and the use of different cultivars.

The evidence presented so far indicates that priming benefits result from an advancement of germination and growth, rather than from inherent differences in the way plants grow. If so, then primed and non-primed plants that emerge on any given day should grow and mature at the same rate. This was tested in the experiments reported in Appendix 3. There was no effect of priming on plants that emerged on the same day on growth, yield or time to flowering and maturity (Appendix 3: Tables 2 & 3, Fig. 4).

3. Recommendation domains (climatic, environmental, socio-economic) for 'on-farm' seed priming clarified using participatory evaluation

3.1 Identify an envelope of conditions where seed priming should be beneficial

Priming of maize is likely to be beneficial in most soil conditions. Although high temperatures (>30 °C) made maize more vulnerable to hypoxia resulting from excessive moisture in laboratory experiments, this does not seem to be such a general problem in the field. There is evidence that interactions with crusts may sometimes lead to much greater benefits of priming than typical, or else to adverse effects on final emergence. At this stage it is difficult to predict these outcomes before sowing. The data that we have on cotton give cause for concern as to whether this crop will generally respond well to priming. However, what we know of the physiology of priming wheat, rice and chickpea is consistent with previous reports that these respond well to priming.

3.2 Participatory evaluation

Across sites, priming led to a significant ($P < 0.05$) increase in maize grain yield in both seasons, despite the two-fold difference in non-primed yield and the range of cultivars tested (Table 4). Priming therefore appeared to offer benefits despite the seasonal differences. Results from the formal survey indicated that 38% of respondents normally prime at least some maize seed but priming was generally used when planting into residual moisture on *vleis* or "to catch up" when gap-filling. Farmers' perceptions of the advantages and disadvantages of priming were explored in detail during the field days and at focus group discussions after farmers had gained more experience of priming seed from the participatory evaluations. The following farmer comments give an overview:

- Emergence of primed seed is one to two days earlier than non-primed seed, although there were occasional reports of slower emergence
- Priming allows planting to be undertaken in drying soils
- Less gap filling is needed when primed seed is used: this saves money
- Primed seed out-competes weeds
- Primed plants grow faster and mature one to two days earlier than non-primed counterparts
- Larger cobs can be harvested from primed plants
- Farmers thought that SC627, SC701 and DK8031 responded well to priming.

Table 4. Effect of seed priming on yield of farmer-managed maize in Masvingo province.

Yield (kg ha^{-1})

	1999-00 (18 farms)	2000-01 (21 farms)
Primed	835	1523
Non-primed	730	1341
% increase	*14%*	*14%*

Analysis of yields showed that varietal differences in response to priming were not significant but it is important to note that all hybrids tested responded positively to priming.

Handling of soaked seed surplus to immediate requirements was perceived as a problem. This is partly associated with the current AIDS epidemic as farmers indicated that they are often called away to funerals at short notice. This is seen to be a problem if seed has been soaked overnight for planting the next day. Since hybrid seed is a major expense the farmers incur in producing maize, they are reluctant to risk losing costly seed.

It is interesting to note that primed crops were associated with increased competitiveness with weeds in both seasons. In the discussions, farmers indicated that in their view primed crops are more vigorous at the seedling stage and are growing faster than crops developing from dry seed. However, their observations from the 1999/2000 year indicate that priming did not decrease the interval between emergence and tasselling/silking (nor was this seen in on-station trials). Two schools of thought emerged about how the use of priming could interact with the timing of weeding operations. On the one hand, some farmers believe that it is important to weed the best maize stands first. This would lead them to weed primed maize first as it has a better plant population and is vigorous. The other view is that because primed maize is thought to be more competitive with weeds, it can be left longer than un-primed stands before weeding is started. In both cases the earlier emergence and increased vigour of a primed stand are the key factors and are clearly seen as an advantage for tolerating weeds.

Labour costs associated with priming are in most cases minimal since a farmer needs only to soak the seed for planting the following day. However, some farmers observed that the seed is sticky so there is a small increase in the time taken to plant. As yields are marginally increased, there will be a corresponding increase in the labour needed for harvesting, transport of cobs and threshing. Economic analysis of the on-farm trials indicated that there are generally net benefits from priming. Net benefits were higher for the well-resourced farmers than poorly-resourced farmers. This is due primarily to better-resourced farmers having better access to draught power and fertiliser which allows them to plant earlier, weed on time and to top dress the crop with nitrogen. However, although poorly-resourced farmers generally achieve lower levels of production, any increase in yield gained without significant cost is likely to be of considerable benefit.

Contribution of Outputs

Previous DFID-funded projects have already demonstrated the utility of 'on-farm' seed priming in increasing yields of target crops in semi-arid areas. This project provides assurance that priming is a scientifically-sound practice that can improve yields through increased crop stand, more rapid seedling emergence and increased uniformity of the stand. Positive responses to priming were seen in a range of soil conditions, farmers' practices and cultivars. This knowledge will help target institutions (some of which, such as CARE Zimbabwe, have been working to trial 'on-farm' seed priming for several years) decide where the technology is most likely to work. The outputs contribute to the project goal of sustainably increased crop production as the risk of crop failure will be decreased and yields increased. It is also possible that understanding gained in this project could be applied to other Production Systems, such as Hillside.

Publications from R7440

Appendix 1. Murungu, F.S., Nyamugafata, P., Chiduza, C., Clark, L.J. & Whalley, W.R. (2003) Effects of seed priming, aggregate size and soil water potential on emergence of cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* L.). Soil and Tillage Research **74**, 161–168.

Appendix 2. Murungu, F.S., Chiduza, C., Nyamugafata, P., Clark, L.J. & Whalley, W.R. (2004) Effect of on-farm seed priming on emergence, growth and yield of cotton and maize in a semi-arid area of Zimbabwe. Experimental Agriculture **40**, 23–36.

Appendix 3. Murungu, F.S., Chiduza, C., Nyamugafata, P., Clark, L.J., Whalley, W.R. & Finch-Savage, W.E. (2004) Effects of 'on-farm seed priming' and sowing occasion on emergence and growth of maize in semi-arid Zimbabwe. Field Crops Research (in press).

Appendix 4. Finch-Savage, W.E., Dent, K.C., Clark, L.J. Soak conditions and temperature following sowing influence the response of maize (*Zea mays* L.) seeds to on-farm priming (pre-sowing seed soak). Field Crops Research (submitted).

Internal Reports

Annual reports to DFID PSP for 1999, 2000, 2001 and 2002.

Participatory evaluation of seed priming experiments - synthesis of three focus group discussions in Chivi communal area (Barura dam), Mushagashe small scale farming area and Zimuto communal area (Maraire). February 2000, Silsoe Research Institute, ref IDG/00/6.

Other Dissemination of Results

Murungu, F.S. (2003) Characterization of seedbed conditions and effects of on-farm seed priming on maize and cotton in semi-arid Zimbabwe. MPhil Thesis. Crop Science Department. University of Zimbabwe, Harare, Zimbabwe.

Clark, L.J., Whalley, W.R., Dent, K., Rowse, H.R., Finch-Savage, W.E., Kaseke, N.E., Murungu, F.S. & Chiduza, C. (2002) 'On-farm seed priming' in maize: a physiological evaluation. Abstract and talk for 7th Eastern and Southern Africa Regional Maize Conference and Symposium on Low-Nitrogen and Drought Tolerance in Maize, Nairobi, February 2002.

As planned, dissemination has been carried out during the project through contact between researchers, practitioners and farmers. This has come about through the planned activities of the project, which included on-farm trials of priming, farmers' days and workshops. One of these workshops included the following talk:

Jasi, L., Gatsi, T., Ellis-Jones, J. & Riches C. (2000) Participatory paired-plot comparison of primed and non-primed maize seed in Zimuto and Mshagashe (1999/2000 season). Pages 8–9 *in* Ellis-Jones, J. & Zvarevashe V., eds. *The Role of Small Dams in the Improvement of Rural Livelihoods in Semi-Arid Areas.* CARE Stakeholder Workshop, 29–31 August 2000, Masvingo, Zimbabwe. ISBN: 0 95312824 5.

Other references

Harris D (1996) The effects of manure, genotype, seed priming and depth and date of sowing on the emergence and early growth of *Sorghum bicolor* (L.) Moench in semi-arid Botswana. Soil & Tillage Research **40**, 73–88.

Harris D, Joshi A, Khan P A, Gothkar P & Sodhi P S (1999) On-farm seed priming in semi-arid agriculture: development and evaluation in maize, rice and chickpea in India using participatory methods. Experimental Agriculture **35**, 15–29.

Appendix 1

Murungu, F.S., Nyamugafata, P., Chiduza, C., Clark, L.J. & Whalley, W.R. (2003) Effects of seed priming, aggregate size and soil water potential on emergence of cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* L.).

Soil and Tillage Research **74**, 161–168.

Appendix 2

Murungu, F.S., Chiduza, C., Nyamugafata, P., Clark, L.J. & Whalley, W.R. (2004) Effect of on-farm seed priming on emergence, growth and yield of cotton and maize in a semi-arid area of Zimbabwe.

Experimental Agriculture **40**, 23–36.

Appendix 3

Murungu, F.S., Chiduza, C., Nyamugafata, P., Clark, L.J., Whalley, W.R. & Finch-Savage, W.E. (2004) Effects of 'on-farm seed priming' and sowing occasion on emergence and growth of maize in semi-arid Zimbabwe.

Field Crops Research (in press)

Appendix 4

Finch-Savage, W.E., Dent, K.C., Clark, L.J. Soak conditions and temperature following sowing influence the response of maize (*Zea mays* L.) seeds to on-farm priming (pre-sowing seed soak).

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