CROP PROTECTION PROGRAMME

Cultivar competitiveness and interactions with on-farm seed priming for integrated weed management

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EXECUTIVE SUMMARY

Studies were undertaken by a number of collaborating institutions to investigate aspects of the role of genotype and interactions with pre-planting seed hydration (seed priming) on the weed competitiveness/tolerance of maize and rice. Laboratory experiments at the University of Wales confirmed that priming hastens time to germination of both crops. A series of field trials, carried out subsequently in Zimbabwe, investigated the effect of maize genotype and priming on crop yield across a gradient of weed pressure. This was achieved by allowing weeds to compete with the crop for varying periods. The dominant effect in all trials was time of weed removal. Priming had a significant, positive effect on yield in only one of four trials. Discussions with farmers indicated that primed seed is often used for gap-filling when emergence is poor or for planting onto residual moisture on *vlei* fields. It is rarely used or planting entire topland fields. In on-farm trials at topland sites priming increased maize yield significantly, by an average of 18% and 14% over the yields of maize grown from dry seed in 1999-2000 and 2000-01 respectively. These results were obtained from farmer managed trials in which the farmers usual weeding practice was used. Field days and farmer focus groups were used to record perceptions of seed priming. The practice is thought by farmers to improve crop emergence. Some consider that young primed maize plants grow faster and are more competitive with weeds. Priming is a low cost practice that provides an opportunity for marginal increases in maize yield. It is recommended that it should be promoted to farmers in Zimbabwe as a component of integrated crop management. Other on-station trials investigated the response of a range of maize genotypes to weed competition. A technique was developed using the natural weed flora but over two seasons no interaction was observed between maize genotype and the duration of weed competition. For the set of maize genotypes investigated therefore, there was no difference in weed competitiveness or tolerance.

Studies were undertaken by the International Rice Research Institute to investigate the potential of seed priming to influence the growth of rice cultivars to enhance yield and improve weed suppression. Experiments were undertaken in the Philippines and Thailand. Laboratory trials in controlled conditions indicated that germination rate was enhanced by priming seeds by a single cycle of wetting and drying. This advantage however did not always translate into improved seedling emergence (rate and stand counts) and depended upon soil moisture conditions and cultivar. In single season studies, seed priming enhanced biomass yield in upland rice in Thailand but conversely no effects were observed in rainfed lowland rice in the dry season in the Philippines when grain yields were measured. Comparative studies of early growth and tillering in rice cultivars, and of weed suppression, suggest that a fuller understanding of the potential benefits of seed priming in rice will come through improved understanding of environmental factors governing cultivar performance.

In a series of field and screenhouse experiments undertaken at the West Africa Rice Development Association, the effects of seed priming on germination, emergence, early plant growth, grain yield and competitive ability of upland rice were investigated. The studies concluded that although seed priming has a positive impact of early germination, subsequent effects on final emergence and yield are variable. It is therefore concluded that local field studies should be conducted before widespread recommendation of this technique in any locality.

PROJECT COLLABORATORS

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CONTENTS

1. Background

Estimates suggest that 18 to 20% of the loss of attainable production of maize and rice in Africa and Asia is attributable to weed infestation (Oerke, 1994). Weed control is therefore a top farmer priority and using either hand tools, or animal draught implements, particularly in resource poor communities, weeding is the most labour consuming pre-harvest operation. For production of maize in sub-saharan Africa, for example, 45-65% of pre-harvest labour use is committed to weeding (Akobundu, 1987). Due to seasonal labour shortages weeding is often delayed or inadequate while women's responsibility and involvement in weeding imposes an additional burden. Consequently participatory studies regularly indicate that farmers regard weeds as a major production constraint in both rice (Adesina, *et al.*, 1994, for West Africa; Moody, 1988 in Asia), and maize (e.g. Riches *et al.*, 1997 for Zimbabwe). With the exception of the high potential irrigated low land rice systems in Asia, smallholder crop producers have not benefited from the revolution in weed control provided by herbicides to high-input systems around the world (Terry, 1996). Other approaches to relieving the drudgery associated with weeding and yield losses associated with "traditional methods" are therefore needed. Weed growth, during the early establishment phase is critical in determining the outcome of competition between the crop and weeds. Cultivars which are adapted to such a weedy environment may therefore have an important role to play, and any interventions which improve early crop vigour could tip the balance of competition in favour of the crop.

Although selection for traits which are associated with weed suppression has not been a prominent feature of crop improvement programmes there is now increasing interest in selecting competitive cultivars. These have been suggested as a component of integrated weed management, facilitating cost effective weed control where there is economic pressure to reduce herbicide use in high input agriculture or to achieve an organic system (Seavers and Wright, 1997; Bond and Grundy, 2001). Studies with a variety of crops, including barley, oats and wheat have demonstrated variability in the competitive ability of cultivars with weeds (De Lucas Bueno and Froud-Williams, 1994; Lemerle *et al*., 1996; Wicks *et al.*, 1986). Greater progress has been made for rice than other row crops. Differences in the response of rice cultivars to weed competition have been reported from Asia (Moody, 1979; Garrity *et al*., 1992) and have been studied in detail at the West Africa Rice Development Association (WARDA) in Côte d'Ivoire (e.g. Johnson *et al.,* 1997). Work at WARDA to select upland rice lines which are competitive with weeds, has demonstrated the competitive advantage of high tiller production for early rapid ground cover, and the correlation of a high leaf area index and specific leaf area with competitiveness (Johnson *et al.,* 1998; Dingkuhn *et al.*, 1999). Dingkuhn *et al.,* (1998) suggest combining (rapid tillering with high SLA during reproductive stages (for high yield potential) to produce an efficient plant type for low-management conditions.

Little research has been conducted on competitiveness of maize genotypes with weeds. Although results have not been entirely consistent, evidence was reported from a number of years' research undertaken by CIMMYT in Zimbabwe that some maize hybrids yield significantly more under heavy weed competition than the cultivars which are commonly used by smallholders (CIMMYT, 1993). Little is known about which maize traits may be associated with weed tolerance but it seems to be associated with early vigour, leading to tall plants during the first four weeks after sowing. More details of the CIMMYT research were published in Zimbabwe subsequent to the commissioning of this project (Waddington and Karigwindi, 1996 – published in 2000). In this four year study weeding regime x maize genotype interaction was not significant at conventionally quoted probability levels ($P>0.05$). Data were presented showing differences in grain yield in unweeded plots at $P>0.12$ to 0.15 while the weed regime x genotype interaction was significant only at $P<0.11$ to 0.12. However compared to the best performing hybrid released in Zimbabwe two CIMMYT hybrids yielded 6.8% higher yield in unweeded plots. The authors concluded that "there are good prospects that hybrids from these populations will have high yields under weed pressure" and "the study…suggests the existence of some variation in the tolerance of maize to competition from weeds early in crop development".

Plants that emerge first in the field have a competitive advantage, and for a crop this can improve selectivity during subsequent weeding operations (Bond and Grundy, 2001). In addition to genotype effects it has been known for many years that pre-sowing treatments can promote rapid establishment – it was hypothesised when the current project was first proposed that faster emergence and establishment should enhance competitiveness and weed tolerance. Interest in the use of pre-sowing treatments involving full or partial hydration of seed dates from the 1870s. Indeed around this time trials in Germany were undertaken with a number of crops, including maize, for which the growth of plants grown from seeds soaked in water for 72 hours and sown moist (Primed) were compared to those grown from dry seed planted at the same time. The primed plants yielded 11% more grain than the controls (Wollny 1885 cited in Kidd and West, 1919). The overall conclusion of work with a number of temperate crops was that primed seed germinates more rapidly than untreated seed. Later work concentrated on a number of species of Gramineae and a number of publications in Europe suggested that soaked seed of a number of grass species germinated better than did untreated samples, and the plants resulting from the former displayed more rapid development. In some cases increases in yield were sufficiently large to suggest priming to be of economic importance e.g. in oats. By 1934 Chippindale remarked that "Although the soaking of grass seeds was formerly carried out frequently by farmers, this procedure in not applied in modern agricultural practice". Subsequent research for temperate agricultural systems led to the development of controlled high-technology methods of pre-soaking and re-drying of seed prior to planting which has been found to be particularly effective in improving crop establishment in cold soils in the spring (Parera and Cantliffe, 1994).

Poor stand establishment of rainfed crops is also one of the major abiotic constraints encountered by resource-poor farmers in semi-arid areas of the tropics. Harris (1996) showed that conditions after sowing had a large influence on emergence and seedling vigour in sorghum. He proposed "on-farm seed priming" as a low cost, low risk intervention which can reduce the time from sowing to crop emergence and which in hot, drying soils typical of marginal rainfall areas can result in better stand establishment. *In vitro* experiments confirmed that seed priming of maize and upland rice for 24 hours significantly hastened germination and the technique was then tested in on-farm trials in India and Zimbabwe (Harris *et al.,* 1999; Harris *et al.,* 2001). Germination tests on a range of West African rice cultivars have shown that germination time can be reduced by as much as 20 hours (nearly 50%) by "priming" - soaking the seed for 12-24 hours prior to sowing (Harris and Jones, 1997). Published results of field trials have been based largely on farmers perceptions of the trials and indicated a number of benefits including two to three days earlier establishment, earlier flowering and grain setting, better drought tolerance and earlier, larger harvests. Work in India demonstrated a significant maize grain yield increase following priming in two of the four cultivars tested. Some farmers also reported that crops developing from primed seed grew more vigorously following establishment and suppressed weeds. In Musikavanhu Communal Area of Zimbabwe for example, approximately 20% of 51 farmers who tested priming considered that priming improved maize competition with weeds and suggested that fewer weedings would be required (Harris *et al.,* 2001).

Following work in India and Zimbabwe the DFID Plant Sciences Research Programme has been promoting seed priming as an easy, low-cost, low-risk practice which does not require equipment or special facilities. Indeed promotional materials produced by PSRP terms priming "a key technology to improve the livelihoods of resource-poor farmers in marginal environments"[1] After priming for pre-determined periods the surface of the seed is air dried and can be handled in the same way as untreated seed. It may also be stored for a few days prior to planting if it is not possible to sow immediately. The "safe limits" for priming can vary with crop and cultivar, but "overnight" is generally safe and effective. This "rule of thumb" has been enthusiastically followed by resource poor farmers in marginal areas of India after only one year's exposure running their own field trials. Here, there has been rapid adoption of priming for rice, maize and chickpea (Harris, personal communication).

[1] *On-farm seed priming*. Leaflet produced in 2001 for DFID Plant Sciences Research Programme. Bangor: University of Wales. pp 15.

Crop Protection Programme-funded work (R6655) supported the development of tillage and weeding technologies for maize production in semi-arid Zimbabwe, undertaken by NRI, Silsoe Research Institute and the Agronomy Institute, Harare. Farmers have shown considerable interest in post-planting ridging with a plough as a labour saving weeding practice (Chatiswa *et al.*, 1997) but have suggested that weeding with the plough can sometimes be delayed when maize plants are growing slowly and are too small. Rapid emergence and early growth could allow more timely and effective weeding. Rapid rural appraisal work in both Save Valley and Masvingo Province has indicated that some farmers already prime maize seed but only when replanting (Chivasa *et al.*, 1997). Seed is primed to allow the plants to "catch up". Thus farmers in Zimbabwe are not unaware of seed priming, but they do not as yet appreciate the potential benefits when used under normal sowing conditions. The need for extra seed for gap filling is perceived as a significant cost by resource poor farmers involved in current participatory trials in Masvingo (Chatiswa *et al.,* 1997). Primed maize seed is also used occasionally when farmers plant onto residual moisture, ahead of the rains, on *vleis* (seasonally flooded valley bottoms), which are common in southern Zimbabwe. These high potential sites carry a heavy weed burden and priming improves crop establishment ahead of the weed growth.

Combining on-farm seed priming with fast-germinating genotypes should enhance competitiveness of high tillering, leafy rice cultivars further and be of considerable benefit to rice growers in a range of environments in which weeds are a problem. Based on the findings of the PSRP there also appears to be potential to consider priming as a component of integrated weed management in maize, particularly if this seed-treatment leads to earlier emergence and fast seedling growth and could be combined with more competitive or at least weed tolerant lines. These were the principles upon which the project work programme was designed.

2. Project Purpose

The project was designed to test the hypothesis that rapid establishment, growth and development of maize and rice are important in determining the outcome of competition with weeds. Through on-station and participatory on-farm trials the project sought to generate information on the use of seed-priming and cultivars with early vigour to enable these to be promoted as a component of weed management. The specific research objectives of the project were 1). To investigate how rapid establishment and early seedling vigour of maize and rice, achieved by combining seed-priming with selected genotypes, contribute to increased competitiveness of the crop with weeds and, 2). To investigate farmers opinions of seed-priming as a weed management strategy. This project was strategic, developing new understanding of the use of seed priming and competitive cultivars for weed management.

3. Research Activities

A number of institutions in UK, Africa and Asia participated in this project. Laboratory work to confirm the response of maize and rice lines to priming were undertaken at the University of Wales, Bangor, under the supervision of Dr D. Harris. Field work on maize in Zimbabwe was co-ordinated by Mr Lawrence Jasi of the Weed Research Team, Agronomy Institute. Socio-economic aspects of on-farm trials in Masvingo Province were addressed by Mr T Gatsi with support from Mr J. Ellis-Jones (Silsoe Research Institute, UK). Following the inception of this project DFID PSRP agreed to support further work which was aimed at understanding the processes involved in seed priming. This project (R7440) involved collaboration with University of Zimbabwe and it was decided to combine resources of both this and the CPP project to implement on-farm studies. To this end the CPP project funded on-farm work in 1999-2000 season while the PSRP project covered costs in 2000-01.

Work on rice was undertaken at West Africa Rice Development Association (WARDA) facility at Bouake, Côte d'Ivoire under the supervision of Dr D Johnson, and at International Rice Research Institute, Philippines, under the leadership of Dr Martin Mortimer.

3.1 Seed germination studies

These were undertaken in the laboratory at Bangor. To inform choice of lines to be used in field experiments, 18 varieties of maize from Zimbabwe and 11 varieties of rice from West Africa were germinated in petri dishes at 30^{o}C in an incubator at the University of Wales, Bangor, to determine their response to seed priming (soaking seeds in water at 30^{o}C for 12 hours followed by surface-drying and sowing). Four replicate lots of 50 seeds of each variety were either primed or not, then set to germinate. Seeds were inspected every six hours, when germinated seeds were counted and removed.

3.2 On-station trials to investigate priming of maize

Two series of trials were conduced at two locations in Zimbabwe. Henderson Research Station, located approx. 40 km from Harare, is representative of Zimbabwe Agroecological natural region II with an annual rainfall in the range of 850-1200 mm. Makoholi Research Station is 40 km north of Masvingo, located on free-draining granitic sands in the semi-arid Natural Region IV with a 25 year (1961-1991) average rainfall rainfall of 583 mm. The first series of trials were designed to examine if pre-plant priming of maize seed has any effect on crop growth, competition with weeds and yield. The following treatments were used for three crop seasons (1998/99 to 2000/01):

<u>Priming</u>: Seed soaked in water at ambient temperature for 12 hours overnight prior to the day of planting. So the seed could be handled it was then spread out to surface dry on a sack or cloth before planting. Primed and dry seed, planted at the same time were compared.

<u>Weed competition</u>: Two times of weeding were used, with weeds removed from 2 weeks following planting or from six weeks following planting. These times were selected on the basis of previous time of weeding trials in Zimbabwe to provide different levels of competition early in the life cycle of maize. The critical period of competition of weeds with maize being generally in the first 6 weeks after planting.

<u>Cultivars</u>: a range of widely grown hybrid maize cultivars were selected. For the first two seasons these were SC 501, R201, R215 and CG4141. These are all classed as “early to very early” maturing in 132-134 days at 1,200 m above sea level. By 2000 R201 which had been a standard cultivar in much of the country for many years was withdrawn from the market due to susceptibility to grey leaf spot. In 2000/01 the trial was re-designed to compare just three cultivars but replication was increased from three to four replicates at each site. CG4141 was retained and two lines DK8031 and SC627, which had performed well in the cultivar screening trial (see below), were added.

Trials were set up in a factorial arrangement as randomised complete blocks. Gross plot size was 8 rows on a 90 cm inter-row space (7.2 by 8.0 m). Target plant population was 37,000 plants ha^{-1} with maize space at 30 cm intervals within the row. The same number of seeds were always planted per row to allow emergence to be monitored. The number of emerging plants were counted on a daily basis, starting at 9 am, until full emergence was achieved. As the season progressed measurements were made of plant height (five plants per plot) at key stages of crop growth as described in the results. Time to silking and tasseling were also recorded. Grain yield was recorded from a net plot of 4 rows, each 4 m long.

3.3 On-station trials to investigate competitiveness of maize with weeds

This series of trials was also carried on for three seasons and included a range of maize hybrids (10) and two open pollinated lines provided by seed companies in Zimbabwe and the CIMMYT research station in Harare. The lines tested varied in maturity length, height and drought tolerance. The objective was to investigate if variation could be detected in the tolerance of the selected lines to weeds as measured by grain yield. In the first season (1998-99) weed pressure was imposed by varying the period of competition from the natural weed flora or from sown stands of the common annual grass weed *Eleusine indica*. This had been used successfully in weed competition studies undertaken in containers at Henderson and it was tested in the field in an attempt to provide a standard level of weed pressure. However, establishment of the grass weed proved a problem, as did subsequent maintenance of the stand. Labourers did not recognise it during the vegetative stage and tended to remove plants along with other weeds. An adequate gradient of weed pressure was achieved with the natural weed flora so subsequent trials used three weeding treatment: Weed free all season; Weedy all season and, weedy for the first six weeks from sowing and weed free subsequently. Treatments were arranges in randomised complete blocks with four replications. Plots were of three maize rows each 5 m long with 90 cm inter-row space and plants seeded at 30 cm spacing in the row. Yield was assessed from a 4 m portion of the centre row. Plant height was also recorded starting 4 weeks after planting and continuing at 3 week intervals up to maturity.

3.4 On-farm studies

These were conducted in Mashagashe Small Scale Commercial Farming Area and Zimutu Commuunal Area in Masvingo Province. These are adjacent to Makoholi and characterised by a maize-based farming system. Farmers prepare land by animal draught ploughing and weed either by hand hoe or with an ox-drawn cultivator. Both areas had previously been used as sites for on-farm trials by previous DFID funded projects on tillage and weed management, implemented by Agronomy Institute. On-farm trials were undertaken in 1999-00 and 2000-01 to allow farmers to assess the value of priming for themselves. In 1999-00 farmers were asked to compare the growth of maize hybrid R201 grown from primed and un-primed seed. The project supplied each farmer with sufficient seed to plant two plots of approximately 10 rows, each 20 m long. Primed and unprimed seed was planted side by side in paired plots. In the subsequent analysis of crop yield each site was considered as a replicate in ANOVA. The trials were managed by the farmers according to their usual nutrient and weed management practices. Farmer group meetings were held in each community at the end of the season to undertaker assessment of the plots and to consider strengths and weaknesses of priming. A questionnaire survey was also undertaken of 25 households in each community in March 2000 (prior to maize harvest) to establish the seed soaking methods, if any, already used and views on the trials. The questionnaire was targeted at the 50 farmers who were provided with seed for a trial. Of these 42 undertook a valid paired plot comparison.

The trials were modified in 2000-01 to include up to four maize cultivars, each planted on plots of 10 rows each 10 mm in length. All farmers were provided with seed of SC513 (137 days to maturity), SC627 (144 days) and SC709 (151 days). The majority also planted SC501 (maturity 134 days) which had become the most commonly planted cultivar in the area. At 8 sites this was replaced by DK8031. Once again trials were farmer managed and assessed by farmers at a group meeting prior to harvest. Yields were recorded from 23 sites by project staff.

3.5 Screenhouse and Field trials with rice

A range of trials were undertaken at WARDA and IRRI. At WARDA the field trials concentrated on determining if priming had an effect on the competitiveness of recently developed upland rice lines. On-farm trials were also undertaken in Côte d'Ivoire. Plots of primed and un-primed rice were included within the institutes' Participatory Variety Selection programme. Work at IRRI first re-visited the effect of different priming treatments on the germination of a range of rice lines. This was followed by screenhouse trials to determine the effect priming on early competition between rice seedlings and weeds. Field experiments were also undertaken in the Philippines and Thailand. Details of sites and experimental protocols will be found in the following sections.

In addition experiments on the effect of priming on rice root growth and competition with weeds at the seedling stage were undertaken as part of an MSc. thesis project at University of Greenwich in 2000-01.

Outputs

4.1. *In vitro* Seed Germination studies at Bangor[2]

The time taken for 50% of maize seeds to germinate is shown in Fig. 1. Germination without priming ranged from less than 40 hours to more than 70 hours. Priming seeds for 12 hours reduced the time for germination in all varieties except SC501. For the varieties that responded positively to priming, the treatment reduced the range of germination times to between 20 and 40 hours. There was a clear relation between "normal", i.e. non-primed, germination and the time saved by priming (Fig. 2). Final germination of all seed lots was not significantly affected by priming (data not shown).

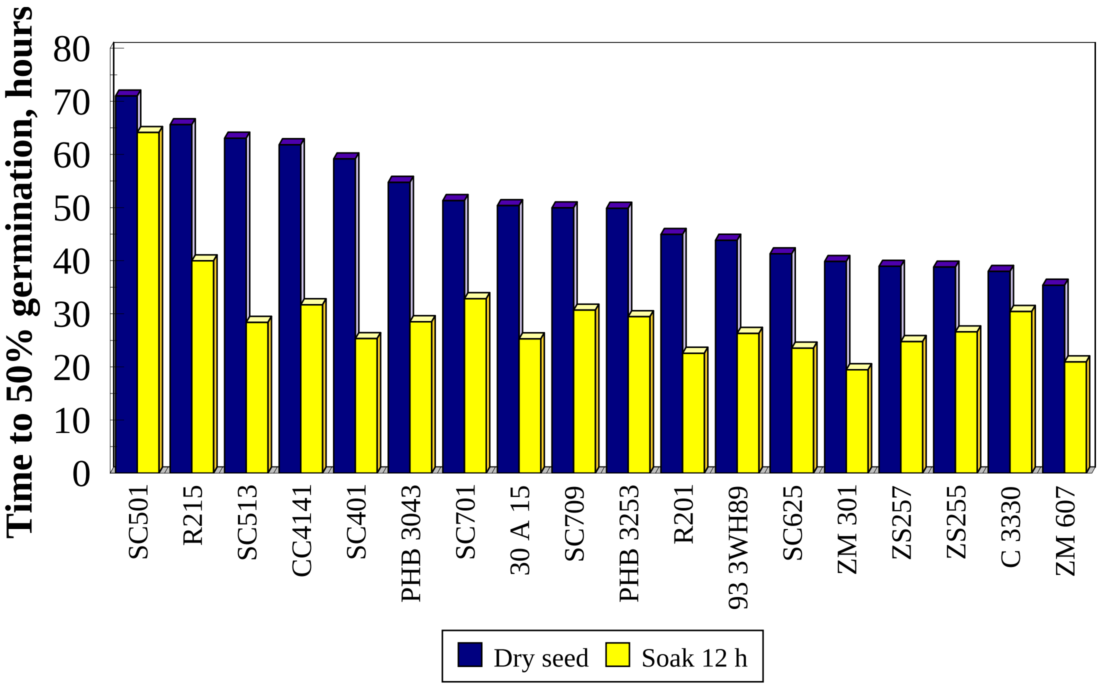


Figure 1. Germination at 30°C of 18 maize varieties from Zimbabwe.

[2] Contributed by Dr D Harris

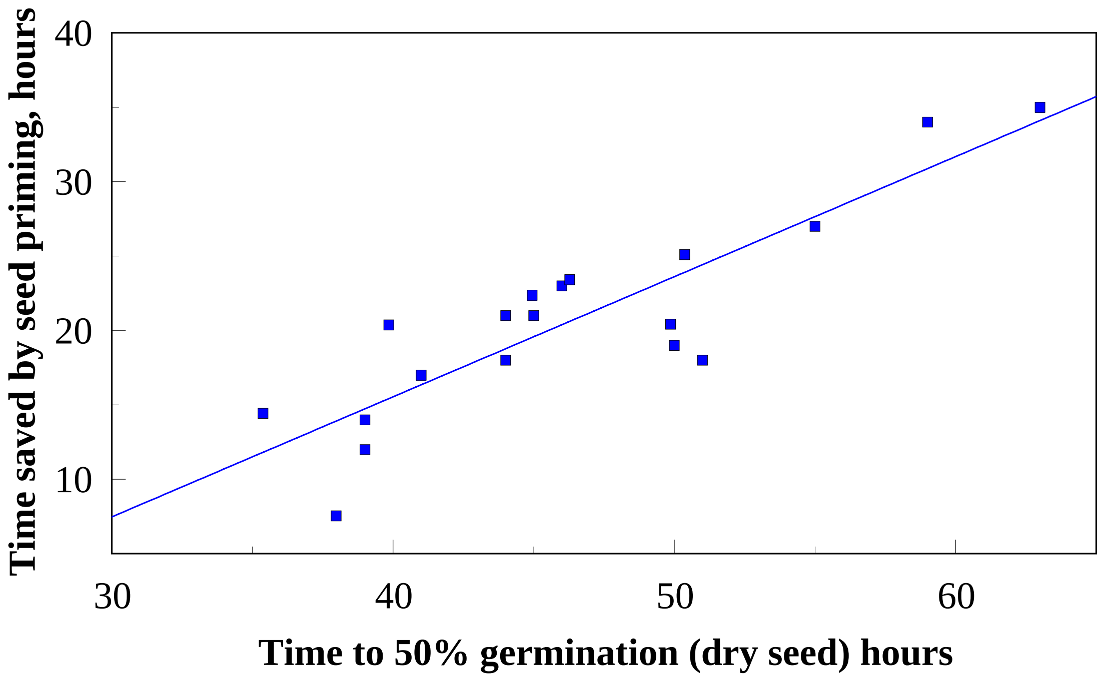


Figure 2. Relation between "normal", i.e. non-primed, germination of maize varieties at 30^{o}C and the time saved by priming seeds in water for 12 hours at 30^{o}C.

The time for 50% germination in rice is shown in Fig. 3. The germination of one variety, WAB-95-B-B-14-HB, did not reach 50% but all other varieties responded to priming in water at 30^{o}C for 12 hours. The response to priming was less marked than in maize. Twelve hours was chosen as the priming time because Indian farmers had indicated that "overnight" was the easiest and most practical soaking time for crops (Harris *et al.*, 1999). Other work (Jones and Harris, 1997; Harris *et al.*, Bangkok meeting; Harris *et al.*, 1999) has shown that a larger response can be safely obtained by soaking maize and rice for up to 24 hours. There was no clear relation, as there was in maize, between the time for "normal" germination and time saved by priming (data not shown).

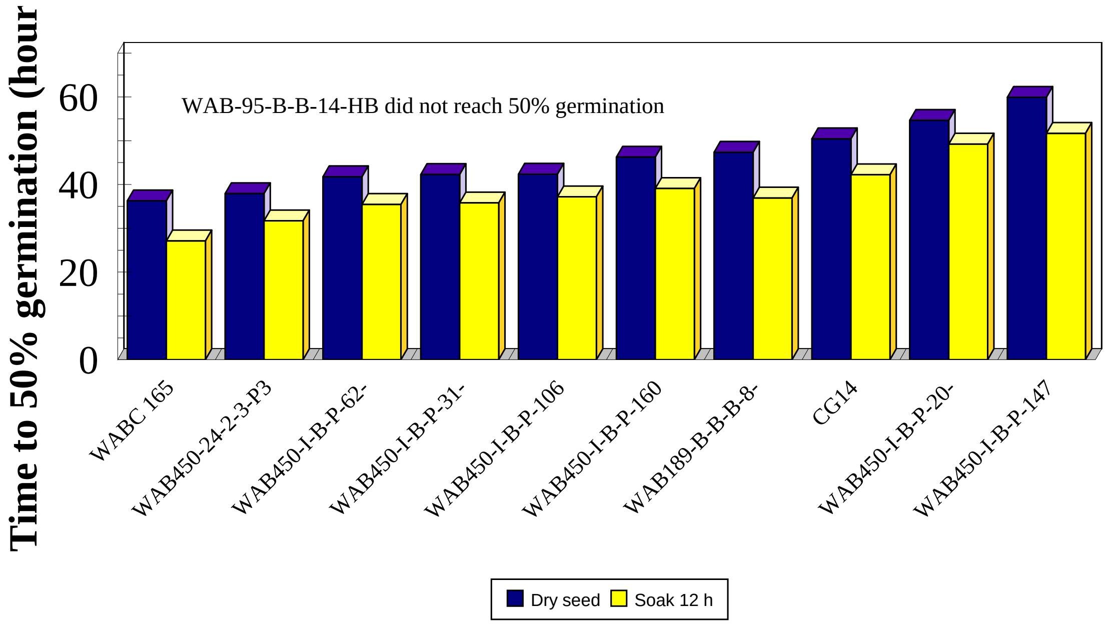


Figure 3. Germination at 30^{o}C of 11 rice varieties from W. Africa.

4.2. Field work on maize in Zimbabwe[3]

4.2.1. On-station trials of seed-priming, weed competition and maize cultivars

Over three seasons of field work four trials, in which the performance of primed and non-primed maize were evaluated, were successfully completed. A trial was also planted at Henderson in 2000/01 but this became heavily infested by maize streak virus and the results are not thought to be reliable. A summary of the significance levels of treatment main effects on yields in the remaining four trials is shown in Table 1.

Table 1. Summary of the effects of seed priming, weed pressure and maize cultivar on maize grain yield (kg ha^{-1} at 12% moisture content) in trials at Henderson and Makoholi Research Stations, Zimbabwe.

		Makoholi		Henderson
	98/99	99/00	00/01	99/00
Weed from 2 weeks	4121	2972	4144	2899
Weed from 6 weeks	2825***	2507***	1075***	2352***
Not primed	3578	2647	2404	2543
Primed	3367^{NS}	2832^{NS}	2815*	2708^{NS}
Cultivar				
SC501	3285	2837	-	2143
R201	3636	2828	-	2855
R215	3182	-	-	
CG4141	3788*	2554^{NS}	2483	2880***
SC627	-	-	2751	-
DK8013	-	-	2595^{NS}	-

ANOVA significance levels in F test. *P = > 0.05; ***P = >0.001 ^{NS} Not significant.

Weed competition was a dominant effect in these trials accounting for between 21 and 83% of the variation as measured by the sum of squares in the ANOVA at Makoholi and 16% in the trial at Henderson. Yields of different cultivars were only significantly different in two trials – at Makoholi in 1998/99 and at Henderson the following year. Priming of seed before planting only had a significant effect in 2000/01 at Makoholi. In this trial yield was increased by 17% (411 kg ha^{-1}) by priming. In the other trials priming accounted for no more than 7% of the variation in the yield data. The precision of the trials is acceptable with coefficients of variation falling below 20% except for Makoholi in 2000/01 when it was 26.2%. The only interaction between treatments was recorded in 1998/99 at Makoholi when the difference between the yield following early or late weed removal was greater for plants grown from seeds which had not been primed (Table 2.). There were no interactions between maize cultivar and priming or maize cultivar and weeding. In this series of trials therefore no evidence was found to support the hypothesis that priming effects the tolerance of maize to weeds. Rainfall distribution was particularly patchy during the 2000/01 growing season when priming had a significant effect on yield. Total October to April rainfall at 628 mm was similar to that in 1998/99 (676 mm) when priming had no effect. However in 2000/01 there was only 21 mm in the period from 4th January to 4th February (22 to 53 days after planting) and little effective rainfall after 13th March. In contrast regular showers fell during the 1998/99 growing season. The first dry spell was from January 15th to 27th (51 to 63 days) when 22 mm fell. Plants would have had more developed root systems with which to exploit moisture stored in the profile than was the case in 2000/01. A possible

[3] Contributed by Dr C Riches, Dr D Harris, Mr L Jasi, Mr T Gatsi and Mr J Ellis-Jones.

explanation of the positive effect of priming on yield in this season could be linked to priming promoting earlier development of the plant root system.

Table 2. Effect of seed priming and date of weed removal on maize grain yield (kg ha^{-1} at 12% moisture content) at Makoholi in 1998/99.

	Non Primed	Primed seed
Weed from 2 weeks	4445	3797
Weed from 6 weeks	2711	2938
S.E.D. (12 d.f.) = 236.9		

The time to 50% emergence of maize was significantly reduced by priming in all trials (Table 3). Across the sites and years priming reduced emergence time by between 1-1.5 days. This is not as large as the difference reported by farmers who participated in on-farm trials in the Sabi valley (Harris *et al.,* 2000), although they do not make accurate measurements but rely on impressions. Final plant stand was not effected by priming.

Table 3. Time (days after sowing) to 50% emergence of maize growing from primed and dry seed sown at the same time.

		Makoholi		Henderson
	98/99	99/00	00/01	99/00
Not primed	5.39	6.18	7.53	6.92
Primed	6.23***	8.22***	9.18***	7.80**

ANOVA significance levels in F test. ** P = > 0.01; ***P = >0.001.

Data from the two trials in 1999/00 demonstrate small effects of priming on maize phenology (Table 4.), although these are probably closely related to differences in emergence data. The interval between tasseling and silking was not effected by priming but time of weed removal did have a significant effect. At Makoholi this was 4.75 days when weeds were removed from 2 weeks after planting but 6.12 days for later weed removal (P>0.001). Corresponding intervals at Henderson were 6.32 and 7.53 days (P>0.001). Improved synchrony, as seen in the earlier weeded plots, may be an important contributor to seed set and higher yields.

Table 4. Days to tasseling and silking of maize as influenced by seed priming at Makoholi and Henderson Research Stations in 1999/00.

	Makoholi		Henderson	
No Prime	72.09	77.75	63.36	70.47
Prime	71.61 NS	76.82 **	62.16 *	68.91 **

ANOVA significance levels in F test. *P = > 0.05; **P = >0.01. NS Not significant.

The effect of treatments on plant height is also illustrated by reference to the data from both sites for 1999/00 (Tables 5 and 6). As with the yield data plant growth, as monitored by height measurements, was significantly effected by time of weed removal. The reduction in growth, when weeds were not removed until 42 days after sowing, was significant by 48 days after sowing. Plants developing from primed seed were initially taller than those from untreated seed but this effect tended to become reduced as the season progressed. At Henderson primed plants were more than 4 cm taller than non-primed counterparts by 27 days after planting. This suggests that the primed stand may appear taller and more vigorous to the farmer so that earlier use of mechanical weeding is possible.

Table 5. The main effects of time of weed removal, priming and maize cultivar (cult) on maize height (cm) at Makoholi Research Station in 1999/00.

	Days after sowing				
	25	48	67	90	111
Weed at 2 weeks	20.2	48.5	70.3	146.2	152
Weed at 6 weeks	21.4 NS	39.9 ***	55.9 ***	145.7 NS	147.3 *
No Prime	20.0	44.2	62.7	149	153.6
Prime	21.8 *	44.2 NS	63.5 NS	143 NS	145.7 ***
Cultivar	***	NS	NS	***	***
Weed*Prime	NS	NS	NS	NS	NS
Weed*Cult	NS	**	***	**	*
Weed*Prime*Cult	NS	NS	NS	NS	NS
CV%	13.8	9.6	10.9	5.3	6.0

Interestingly, there was an interaction between weeding time and maize cultivar at Makoholi. The height of lines R201 and CG4141 were reduced by late weed removal significantly more than the height of SC501 (Table 7).

Table 6. The main effects of time of weed removal, priming and maize cultivar (cult) on maize height (cm) at Makoholi Research Station in 1999/00.

	Days after sowing			
	27	48	69	117
Weed at 2 weeks	28.0	75.2.	180.3	193.8
Weed at 6 weeks	29.0^{NS}	61.0***	162.8***	178.4***
No Prime	26.8	65.5	165.9	183.9
Prime	30.3*	70.6*	177.2*	188.3^{NS}
Cultivar	NS	NS	NS	*
Weed*Prime	NS	NS	*	NS
Weed*Cult	NS	NS	NS	NS
Weed*Prime*Cult	NS	*	*	**
CV%	12.3	13.3	10.2	6.7

Table 7. Effect of time of weed removal on height of three maize hybrids at 67 days after sowing at Makoholi Research station in 1999/00.

	Cultivar		
	SC501	R201	CG4141
Weed from 2 week	65.4	70.0	76.5
Weed from 6 week	59.5	55.4	52.7
S.E.D. (44 d.f.) = 3.08			

4.2.2. Effect of time of weed removal on yield of maize lines

The time of weed removal was the dominant factor effecting maize yield at both Makoholi and Henderson Research Stations in this series of trials (Table 8). Yield also varied significantly between cultivars but no interaction between weeding time and cultivar was recorded. This suggests that for the set of maize genotypes tested there is no difference in response to weed competition.

Table 8. Main effects (significance levels from ANOVA F test) of time of weed removal and cultivar on maize grain yield at Makoholi and Henderson Research stations.

	Makoholi		Henderson	
Treatment	1999/00	2000/01	1999/00	2000/01
Weeding	<0.001	<0.001	<0.001	<0.001
Cultivar	0.016	0.4	0.018	0.018
Weeding*Cultivar	0.328	0.884	0.144	0.404

Table 9. Main effect of duration of weed competition on yield (kg ha^{-1}) of maize cultivars

	Makoholi		Henderson	
Treatment	1999/00	2000/01	1999/00	2000/01
Weed free	4131	5353	8228	2844
Weed free from 6 weeks	3873	2890	4358	1279
No weeding	838	320	1333	839
SED (d.f.)	185 (101)	196 (105)	365 (101)	196 (96)

The three levels of weed competition used in the trials resulted in a steep gradient of yields at both sites (Table 9) suggesting that the technique used would be adequate to distinguish between competitive ability of maize lines. In terms of absolute yield under season long weed competition and yield expressed as a % of the corresponding weed free yield a number of lines performed relatively well (Table 10). These included DK8031, PHB3253, R215, SC501 and SC627. The severest yield loss due to weeds was observed at Makoholi in 2000/01. In this particular trial the yield when weeds were allowed to complete with the crop for the first six weeks after planting were above 3000 kg ha^{-1} and at least 60% of the weed free yield for four entries including SC501 and SC627. SC501 is widely grown in Masvingo province. The yield of DK8013 was 50% the weed free yield of 5296 kg ha^{-1}.

Table 10. Yields of maize cultivars under season long weed competition (kg ha^{-1} at 12% moisture content) and as % of yield when kept weed free.

	Makoholi				Henderson			
	1999/00		2000/01		1999/00		2000/01	
Cultivar	Weedy yield	% weed free yield	Weedy yield	% weed free yield	Weedy yield	% weed free yield	Weedy yield	% weed free yield
R201	943	24	-	-	1036	12	-	-
R215	1000	21	-	-	1645	18	-	-
CG4141	746	16	471	9	1275	15	427	18
DK8031	1176	28	198	4	1972	24	918	24
ZM301	452	13	-	-	1338	25	250	14
ZM607	549	14	-	-	1311	16	-	-
PHB30R65	806	16	319	6	856	12	822	40
PHB 3253	1079	29	287	5	1004	11	582	18
SC501	767	20	684	14	1333	17	1215	50
SC513	485	12	400	7	1052	12	843	30
SC627	1331	39	371	8	1537	20	1094	32
SC701	722	15	-	-	1632	17	-	-
SC709	-	-	210	3			1943	64
AC31	-	-	287	6			410	13
AC71	-	-	0	0			-	-
SED (d.f.)	640	-	680 (105 d.f.)		1012		1294 (96 d.f.)	

4.3. On-farm trials in Masvingo Province

4.3.1. Effect of priming on maize yields

Across sites priming led to a significant increase in maize grain yield in farmer managed crops in 1999-2000. On average primed yields were 105 kg ha^{-1} higher than those from un-primed maize, an 18% increase. The distribution of yields and % yield difference between non-primed and primed crops is shown in figures 4-6. With the exception of three sites, priming had a positive effect on yield.

Table 11. Effect of seed priming on yield of farmer managed maize on 18 farms in 1999-2000.

Treatment	**Yield kg ha^{-1}**
Prime	835
No Prime	730
P	0.018
S.E.D. (17 d.f.)	40.3

Priming also significantly increased yields across farms in the following season (Table 12) when the seed treatment increased maize grain yield by an average of 182 kg ha^{-1} (13.6%). There was no significant difference between the yields of the individual cultivars (Tables 13 and 14) despite their somewhat different durations. SC627 and SC709 are medium and long season cultivars, maturing at 144 and 151 days respectively at 1200 m. These are not generally recommended for the marginal rainfall conditions of Natural region IV where an early maturing type, e.g. SC513 (maturing at 137 days) would be preferred. There was no cultivar x priming treatment interaction, suggesting that priming may be effective for all cultivars under farmer management.

Table 12. Effect of seed priming on yield of farmer managed maize on 21 farms in 2000-01. Combined analysis for all cultivars.

Treatment	**Yield kg ha^{-1}**
Prime	1523
No Prime	1341
P	0.023
S.E.D. (142 d.f.)	79.2

Table 13. Effect of seed priming on yield of farmer managed maize on 21 farms in 2000-01.Data for primed and unprimed plots of the three cultivars grown at all sites.

Cultivar	Prime	No Prime	Mean
SC513	1562	1427	1495
SC627	1476	1209	1343
SC709	1567	1428	1497
Mean	1535	1355	
P for cultivars	0.23		
P for prime	0.034		
P for interaction	0.769		
SED for prime (96 d.f.)	83.7	SED for cultivars (96 d.f.)	102.6

Table 12. Effect of seed priming on yield of farmer managed maize in 2000-01. Analysis of data sub-set for 8 farms with four cultivars in common:

Cultivar	Prime	No Prime	Mean
SC513	1579	1208	1394
SC627	1485	1151	1318
SC709	1737	1303	1519
DK8031	1304	1209	1257
Mean	1526	1217	
P for cultivars	0.468		
P for prime	0.015		
P for interaction	0.774		
SED for prime (47 d.f.)	121.9	SED for cultivars (47 d.f.)	172.4

It is striking that the average yield increase of 14% due to priming in these trials is the net result from a set of highly variable trials. It is also of note that this variability was not systematic with respect to variety as there was no significant different between varieties nor any interaction between variety and priming. There were significantly more positive results (57) than negative (25) ones, and there were 20 trials in which priming gave a benefit of more than 50%, whereas only one trial resulted in more than a 50% decrease due to priming.

Any analysis of perceived risk will depend on the assumptions made to evaluate yield criteria. A common assumption is that a 10% difference in yield is not considered of significance in farmers' perception of their field trials. If this criterion is applied to the trials data in Fig 7, 50 trials gave more than a 10% yield advantage due to priming, 13 were between minus 10% and plus 10% (i.e. not different) while 19 trials resulted in more than a 10% yield decline following priming.

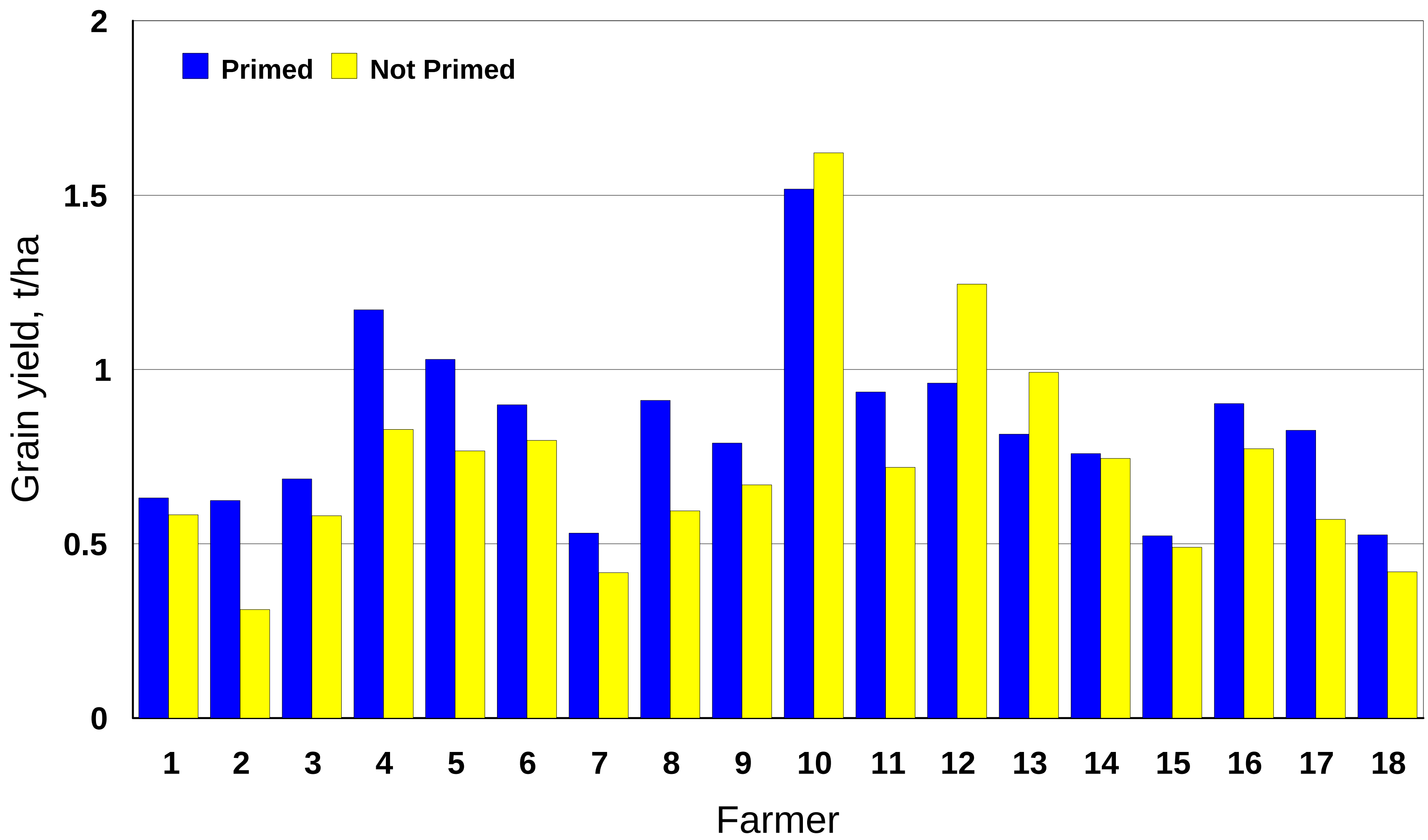


Figure 4. Grain yields with and without priming from 18 farmer managed crops in 1999-2000.

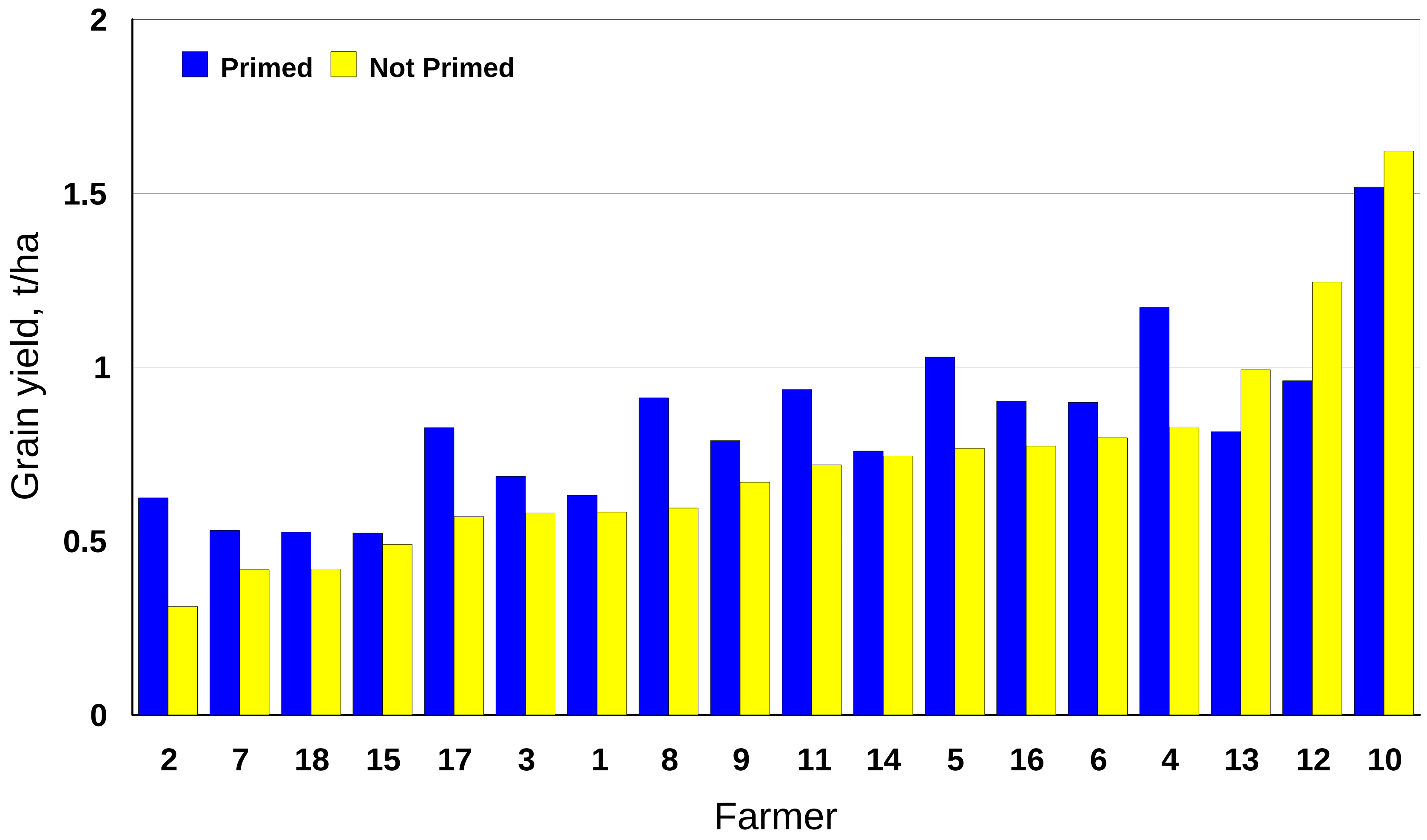


Figure 5. Grain yields from 18 on-farm trials ordered by the yield of the non-primed plot (1999-2000).

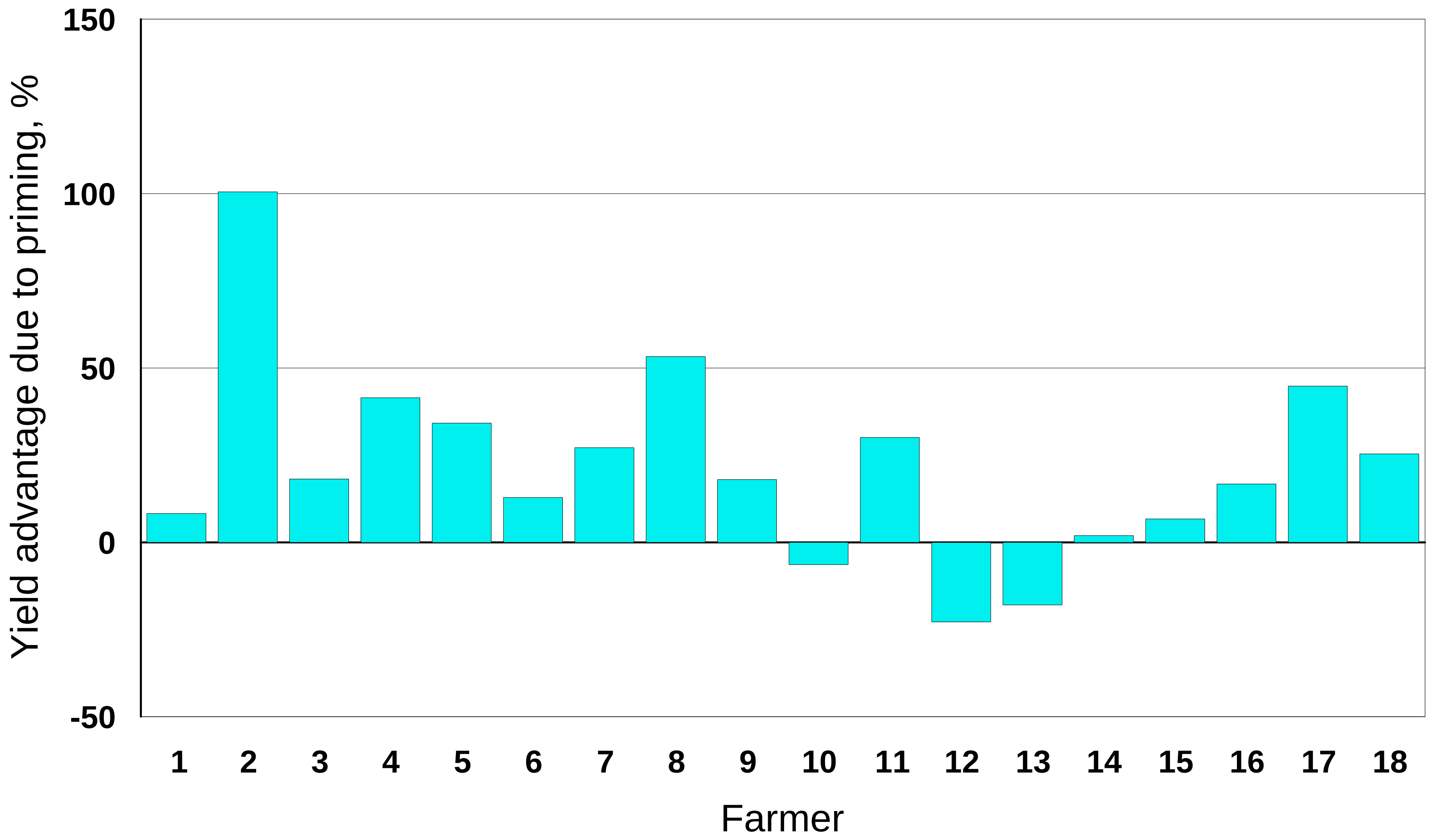
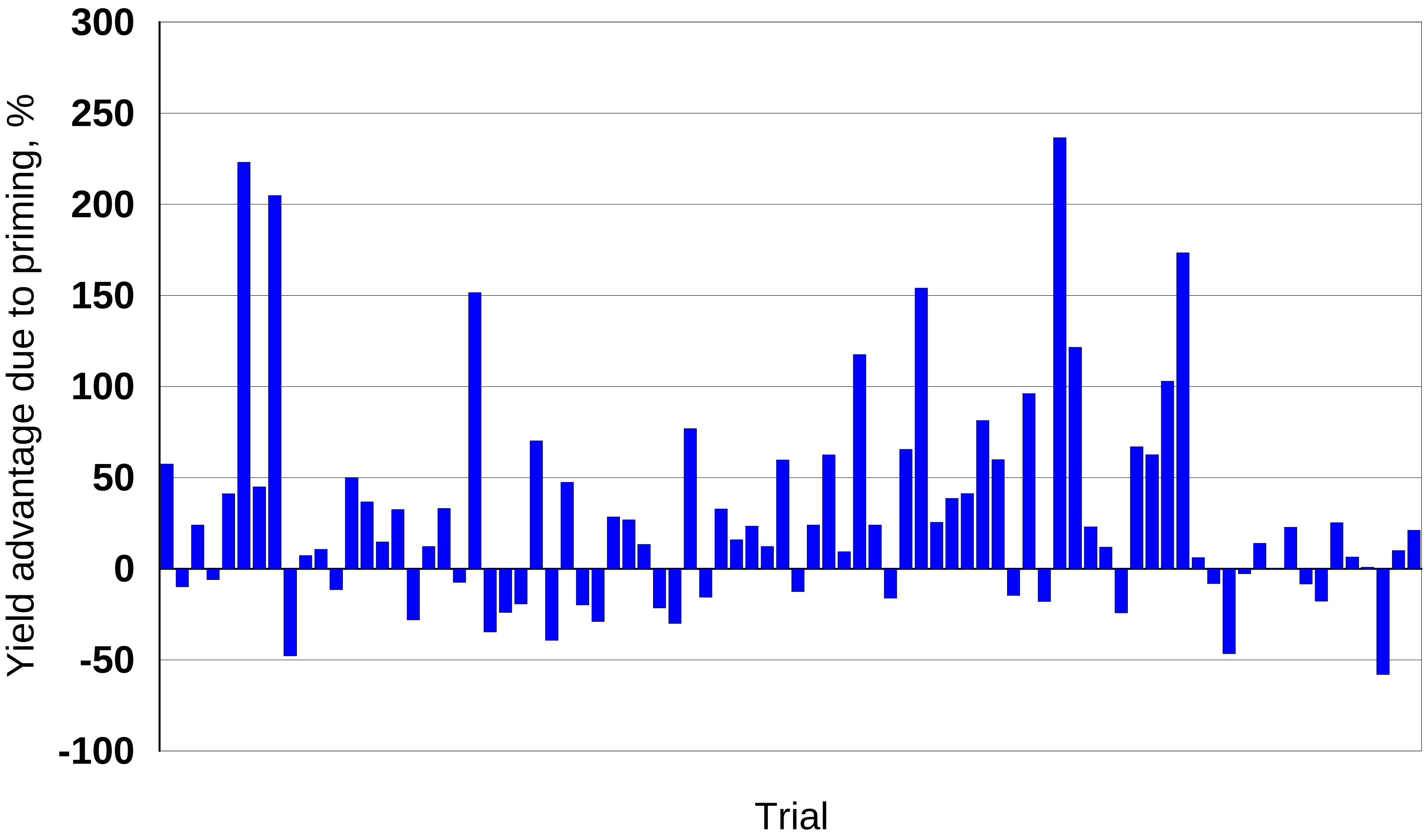


Figure 6. Maize yield from primed plots in 18 on-farm trials expressed as the percent change over non-primed plot (1999-2000).

Figure 7. The percent yield advantage due to priming of each of 82 paired-plot trials in 21 farmers' fields in the 2000-01 season. Each trial consisted of two plots, both sown with seed of one of seven maize varieties, with primed seed used in one of the plots and non-primed seed used in the other.



4.3.2. Socio-economic studies and farmers perceptions

Discussions with farmer groups at field days prior to harvest each year and a formal questionnaire survey of trial participants, conducted in March 2000, were used to establish the present use of seed soaking in Mshagashe and Zimuto and, farmers views on the trials and priming. Focus group discussions were also undertaken with a farmer group in Chivi Communal area in 2000 in collaboration with CARE Zimbabwe who had also undertaken demonstration/trials with primed and un-primed maize. Detailed results have been presented in one report[4] and one workshop paper[5]. Some of the main findings are summarised here.

Table 13. Characteristics and resource availability of households participating in on-farm trials at Mshagashe and Zimuto.

	Well Resourced	Average resources	Poorly resourced	Very poor resources
Group	RG1	RG2	RG3	RG4
Number in sample	22	11	11	6
Male head %	77	55	27	17
Own plough %	100	100	100	50
Own cultivator %	100	46	36	0
Cattle owned	86% 8+	55% 8+	27% 8+	50% nil
Always use fertiliser %	65	60	55	17
Area cropped ha	7-10	3-6	1-3	1-3
Prime seed %	43	20	55	33

Farmers from a range of household categories, including those with a full range of draft power and implements and those without, were involved in the trials (Table 13). The perceptions recorded are therefore likely to be representative of the farming community. Overall some 38% of respondents indicated that they normally prime maize seed. Those who did not indicated that they either lacked the knowledge, stated that "it is not our practice", or indicated that it was too time consuming. Both purchased and farm saved maize seed is soaked. Of those who reported priming, 16% soak all their seed, 21% about half, 26% about one quarter and 37% soak sufficient for gap filling only. Where priming is already undertaken most farmers soak the seed for more than 12 hours. The practice is most usually used for planting on to residual moisture *vlei* soils. These are seasonal wetlands where the crops are established ahead of the rains. Only 10% of farmers said they used primed seed on the sandy topland soils which are planted following rain. By and large farmers use primed seed for gap filling after crop emergence rather than for planting whole fields. This is consistent with farmer practice in other areas of Zimbabwe e.g. as reported in Sabi Valley (Harris, personal communication). Priming is therefore used to improve crop emergence and ensure an adequate plant stand – either when planting into residual moisture or "to catch up" when gap filling. The majority of the trials were planted on sandy to sandy loam soils (81%) and nearly all (95%) were sown after rain into moist soil.

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[4] *Participatory Evaluation of Seed Priming Experiments*. Report IDG/00/6, Silsoe Research Institute, February 2000

[5] Jasi, L. *et al.*, (2000) Participatory-paired plot comparison of primed and no-primed maize seed in Zimuto and Mshagfashe. In: *The role of small dams in the improvement of rural livelihoods in semi-arid areas*. CARE stakeholder workshop, Report IDG/00/18, Silsoe Research Institute, August 2000.

Table 14. Farmers perceptions of advantages and disadvantages of priming maize. % farmers mentioning each issue.

Advantages	Disadvantages
➢ Earlier emergence (80%)	➢ Poor germination (24%)
➢ Better crop stand (24%)	➢ Seed difficult to handle (24%)
➢ Improved crop growth (22%)	➢ Increased pest damage (10%)
➢ Less competition from weeds (14%)	➢ Seed dressing is lost (10%)
➢ Crop better able to withstand drought (6%)	➢ Unused seed wasted (8%)
➢ Earlier planting is possible (4%)	➢ Seed rots easily (6%)
➢ Fewer weeds in primed plot (4%)	➢ Also mentioned seed may not emerges and additional labour needed
➢ Increased crop yield (4%)	

Farmers perceptions of the advantages and disadvantages of priming were explored in detail during the field days and at focus group discussions. A quantitative estimate of the importance of the main issues raised by farmers was obtained from the questionnaire (Table 14). These were the views after the first season of trials when a number of farmers would have been unfamiliar with priming for use on a field scale at initial planting of topland. Problems of handling and seed wastage are likely to be overcome with increased familiarity with the technique. Increased pest damage on primed seed is partly due to it being more attractive to seed eating birds.

At the field days held in Mshagashe and Zimuto prior to the second season of trials the following farmer comments were recorded:

- emergence of primed seed is one to two days earlier than non-primed seed, even when soil moisture is low; use of priming allows planting to be undertaken in drying soils;
- Less gap filing is needed when primed seed is used – this saves money;
- Primed seed out-competes weeds;
- Primed plants grow faster and mature earlier than non-primed counterparts;
- Larger cobs can be harvested from primed plants;
- Farmers thought that SC627, SC70I and DK8031 responded well to priming;

Handling of soaked seed which is surplus to immediate requirements was still 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. Hybrid seed is one of the main expenses the farmers has for crop establishment and they are reluctant to risk loosing 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. 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 need only to soak the seed for planting the following day. However, some farmers observed that the seed can be 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. The economic analysis of the on-farm trials reported in Jasi *et al.*, (2000) indicates that there are generally net benefits from priming. Net benefits were higher for the well resourced farmers (RG1) at around Z$1500 ha^{-1} compared to Z$250 or less for RG2 and RG3. This is due primarily to the formers better access to draught power and fertiliser which allows them to plant early, weed on time and to top dress the crop with nitrogen. However, at their generally lower level of production and income any marginal increase in yield gained with out significant cost is likely to be of considerable importance to poorer households.

4.4 STUDIES ON RICE AT IRRI[6]

Experiments were conducted to examine the effects of seed priming (*sensu* Harris *et al.*, 1999) on:

1) improved germination in rice germplasm;
2) cultivar performance and yield in field conditions;
3) cultivar suppression of weeds.

Experiments were conducted at IRRI, Los Banos, Philippines, in Samoerang Upland Rice and Temperate Cereal Crop Experiment Station, Thailand and at the Central Rainfed Upland Rice Research Station Hazaribag, India. This report covers experiments at the first two sites and a termination report for work in India will be forwarded on final receipt of all results from collaborators.

4.4.1. EXPERIMENT 1. AN EXAMINATION OF PRIMING TREATMENTS

A partially factorial combination of seed soaking and drying treatments prior to germination was examined. Seeds were soaked in water for varying lengths of time and then dried either in an oven for 24 h at constant temperature, or in the laboratory, or surface dried (Table 15), being weighed before and after the priming treatment. They were then enclosed in permanently moist filter paper at 30°C in darkness and germination (emergence of the radicle) recorded every 24 h.

Three cultivars were examined: IR55423-01 (upland rice cultivar, cv), PSBRc68 (cv adapted to rainfed lowlands) and IR72 (cv for irrigated conditions). All seed stocks were less than 6 months old and five replicates, containing 100 seeds, were used in each treatment.

Table 15. Priming treatments.

Treat no.	Soaking time (h)	Drying time (h) and temperature
	0	A : Not applicable (equivalent to treatment 2)
1	0	B : 24h at constant 35^{o}C
2	0	C : 24h laboratory ambient temperature 28 - 30^{o}C
3	12	A : Surface drying
4	12	B : 24h at constant 35^{o}C
5	12	C : 24h at laboratory ambient temperature 28 - 30^{o}C
6	24	A : Surface drying
7	24	B : 24h at constant 35^{o}C
8	24	C : 24h laboratory ambient temperature 28 - 30^{o}C

[6] Contributed by Dr M. Mortimer

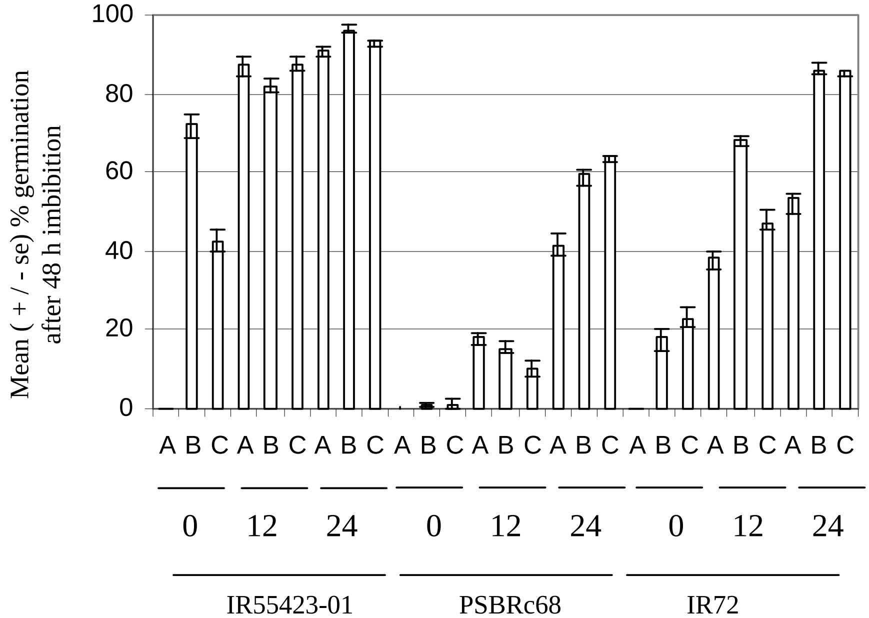
Priming treatments altered the initial seed weight at the start of the imbibition period (Table 16), over 0.003 and 0.004 g water being absorbed per seed when soaked for 12 and 24 h respectively. Seeds dried in the laboratory (B) tended to retain more water than when dried at constant 35°C (C) but were of similar weight to unsoaked seeds at the start.

The subsequent speed of germination, as measured by the number of seeds germinated after 48 h imbibition, differed significantly amongst cultivars in relation to soaking and drying ($P<0.001$, ANOVA). Drying treatment B applied to unsoaked seeds significantly improved germination of cv IR55423-01 only. Germination was highest in all three cultivars in seed lots dried after soaking for 24 h, with no significant differences between drying methods B and C (Fig. 8). There were no significant differences in total germination (over 95%) due to treatments or cultivars after 144 h germination. In all subsequent experiments, priming refers to soaking seeds in water for 24 h and drying at 35°C for a further 24 h.

Table 16. Changes in total seed weight in response to priming. See Table 15 for details of treatments.

Cultivar	Soaking (h)	Drying treatment	Mean change in weight of 100 seeds (g)	S.E.
IR55423-01	0	A	-	-
	0	B	-0.030	0.003
	0	C	0.020	0.003
	12	A	0.370	0.004
	12	B	0.064	0.064
	12	C	0.076	0.004
	24	A	0.468	0.010
	24	B	0.080	0.008
	24	C	0.080	0.008
PSBRc68	0	A	-	-
	0	B	-0.038	0.002
	0	C	0.012	0.002
	12	A	0.398	0.012
	12	B	-0.004	0.002
	12	C	-0.112	0.195
	24	A	0.516	0.002
	24	B	0.006	0.002
	24	C	0.068	0.015
IR72	0	A	-	-
	0	B	-0.036	0.002
	0	C	0.014	0.008
	12	A	0.372	0.007
	12	B	-0.020	0.005
	12	C	0.050	0.029
	24	A	0.430	0.004
	24	B	-0.018	0.006
	24	C	0.044	0.002

Figure 8. Seed germination after 48 h imbibition in response to priming treatments.



4.4.2. EXPERIMENT 2. A COMPARISON OF UPLAND AND RAINFED LOWLAND CULTIVARS

Forty-five cultivars (Table 17) were examined, seeds being either primed (soaked in water for 24 h and then dried for 24 h at 35°C), or unprimed, (dried alone for 24 h at 35°C). Seed lots were then germinated at a constant 30°C following similar procedures to that in Experiment 1Seeds ungerminated after 256 h were tested for viability using tetrazolium chloride.

Table 17. Number designations of cultivars examined.

Number	*Upland cultivars*
1	PSBRC 5
2	IR55423-01
3	UPLRi-5
4	AZUCENA
5	IRAT 104
6	IR60080-46A
7	DINORADO
8	AUS 196
9	VANDANA
10	C22
11	CNA 4136
12	MOROBEREKAN
13	TOYO HATA MOCHI
14	WAB 181-18
15	IAC I65
Number	*Rainfed lowland cultivars*
1	KDML 105
2	MAHSURI
3	TCA48
4	SABITA

5	IR69513-11-SRN-1-UBN-3-B
6	SBIR67440-M-5-1-1-1-1
7	SBIR67495-M-2-1-1-1-1
8	IR70182-24-PMI-2-1-1
9	Rc 14
10	Rc 60
11	IR68851-27-1-B-1-2-1
12	IR69504-48-SRN-2-UBN-1-2
13	IR70175-51-2-1-1-2
14	IR68098-B-78-2-2-B-1-2
15	IR68835-44-7-B-B-5-1
16	IR68853-3-1-3-1-1
17	IR70168-39-PMI-7-B-1-2-3
18	IR70173-30-SRN-3-UBN-1-1-2-1
19	IR70174-14-SRN-4-UBN-2-B-1-2
20	IR70175-3-5-1-2-1-1
21	IR70181-26-PMI-1-UBN-1-B-1-1
22	IR70181-32-PMI-1-1-4-2
23	IR70212-2-2-B-1-1
24	IR70213-10-CPA-4-2-3-2
25	IR70215-15-CPA-2-UBN-1-1-2-2
26	IR70215-45-CPA-6-UBN-B-1-3-2
27	IR70215-4-CPA-1-UBN-1-1-3
28	IR70224-1-7-1-1-1-1
29	IR70844-12-2-B-1-1
30	IR68840-57-1-2-2

All seed stocks of upland cultivars had high germination capacity (>96%) Table 18, and analysis of variance indicated highly significant effects of cultivar, priming treatment and their interaction ($P < 0.001$). Variation in speed of germination was noticeable amongst cultivars; priming improved germination across a range of 24 – 80% (Table 18). Rainfed rice cultivars exhibited variable germination capacity, two seed stocks showing up to 30% inviability and four exhibited dormancy. Overall, priming increased the rate of germination (Table 19) and there were significant sources of variation due to cultivar, priming and cultivar response to priming ($P < 0.001$). However the responsiveness was generally much reduced in these cultivars as whole, and in some, priming reduced the germination rate.

Table 18. Germination responses to priming in upland rice cultivars.

Cultivar	Treatment	Mean % germination after 30 h incubation	S.E.
1	Unprimed	60.00	2.08
	Primed	94.33	2.18
2	Unprimed	29.66	1.20
	Primed	77.66	5.78
3	Unprimed	32.33	8.81
	Primed	78.66	1.20
4	Unprimed	64.33	5.84
	Primed	91.33	0.33
5	Unprimed	3.66	0.66
	Primed	38.66	1.45
6	Unprimed	8.00	1.52
	Primed	46.00	1.52
7	Unprimed	2.33	0.66
	Primed	37.00	4.58
8	Unprimed	1.33	0.33
	Primed	25.33	2.33
9	Unprimed	64.00	5.50
	Primed	92.66	1.85
10	Unprimed	68.66	2.72
	Primed	54.66	15.24
11	Unprimed	11.66	2.60
	Primed	82.00	14.64
12	Unprimed	3.66	0.33
	Primed	85.33	1.33
13	Unprimed	0.66	0.33
	Primed	43.66	2.40
14	Unprimed	0.66	0.33
	Primed	33.00	2.01
15	Unprimed	7.33	2.02
	Primed	66.33	1.45

Table 19. Germination responses to priming in rainfed lowland cultivars.

Cultivar	Treatment	Mean % germination (corrected for viability) 30 hrs after incubation	S.E.
1	Unprimed	1.9	0.48
	Primed	0.8	0.85
2	Unprimed	92.3	3.85
	Primed	94.2	2.91
3	Unprimed	0	0
	Primed	0	0
4	Unprimed	85.4	3.75
	Primed	92.2	3.18
5	Unprimed	6.8	1.91
	Primed	5.2	1.05
6	Unprimed	0	0
	Primed	19.0	0.49
7	Unprimed	4.4	1.06
	Primed	71.3	0.88
8	Unprimed	85.9	6.52
	Primed	94.6	0.34
9	Unprimed	93.2	1.90
	Primed	98.9	0.62
10	Unprimed	80.3	0.67
	Primed	93.9	1.29
11	Unprimed	95.5	0.89
	Primed	99.3	0.66
12	Unprimed	85.6	1.19
	Primed	97.2	1.85
13	Unprimed	63.7	4.30
	Primed	92.6	0.60
14	Unprimed	97.5	0.70
	Primed	80.6	4.33
15	Unprimed	76.3	9.81
	Primed	94.9	1.54
16	Unprimed	47.2	2.49
	Primed	94.9	1.70
17	Unprimed	42.3	1.85
	Primed	94.5	2.10
18	Unprimed	74.9	3.05
	Primed	96.2	1.23
19	Unprimed	44.8	1.29
	Primed	19.6	1.04
20	Unprimed	75.4	3.42
	Primed	68.9	5.40
21	Unprimed	89.2	1.53
	Primed	88.4	0.75
22	Unprimed	98.7	0.68
	Primed	97.0	0.35

Table 19 cont.

23	Unprimed	92.5	1.92
	Primed	60.3	11.80
24	Unprimed	93.8	3.71
	Primed	96.3	0.71
25	Unprimed	83.6	8.93
	Primed	95.0	2.37
26	Unprimed	84.6	2.74
	Primed	87.5	3.55
27	Unprimed	66.5	3.60
	Primed	50.7	8.51
28	Unprimed	2.8	0.98
	Primed	79.6	1.27
29	Unprimed	97.3	1.40
	Primed	96.9	0.95
30	Unprimed	20.3	12.96
	Primed	95.4	2.30

4.4.4. EXPERIMENT 3. THE EFFECT OF PRIMING ON YIELD IN RAINFED RICE

A field trial was conducted on the upland farm at IRRI, Los Banos during the dry season from January to March 2000 on a Maahas clay soil. The experimental design employed a split-split plot arrangement of treatments with three replicate blocks. Main plots were cultivars (4), subplots weeding treatments (3) and sub-sub-plots, priming (2). Sub-sub plots were 3 x 4 m in size. Weeding treatments comprised manual weeding either once at 10 DAE, or twice, 10 and 24 DAE, or three times 10, 24 and 40 DAE. Seeds of each cultivar were primed or unprimed and sown by hand at a seeding rate of 80 kg seed / ha (rates adjusted viability) in rows spaced 25cm apart. Cultivars were chosen to reflect differences in response to priming.

	Cultivar	Code in Table 18	
1	IR70213-10-CPA-4-2-3-2	24	
2	IR68840-57-1-2-2	30	Responsive
3	IR69504-48-SRN-2-UBN-1-2	12	
4	IR70168-39-PMI-7-B-1-2-3	17	Responsive

Plots were irrigated twice a week with a Perforain irrigation system that gave an aerial water supply for 1 h. This was suspended if rainfall had occurred in the previous day. Characteristically, plots were flooded to a depth of up to 20 mm after irrigation but water disappeared by percolation over the next 3 h.

Fertilizer (40kg N per hectare) was applied at 13 and 33 DAE. Furadan and Benlate was applied 18 DAE. In each sub-sub plot weed and rice counts were made every day for the 7 days following sowing and row counts (2 x 25cm rows) made at 7, 14, 21 and 27 DAE together with measurements of plant height (measured from soil surface to tip of tallest leaf). Tiller counts were taken 7, 12, 27 42 and 68 DAE together with destructive samples at each occasion, biomass being separated into stem and leaf. Total biomass and grain yields were measured at harvest.

Weed biomass estimates by species were taken prior to imposition of weeding treatments. The weed flora comprised: *Calopogonium muconoides, Chloris barbata, Cleome rutidosperma, Commelina diffusa, Corchorus olitorius, Cynodon dactylon, Cyperus iria, Cyperus rotundus, Digitaria ciliaris, Echinochloa colona, Eclipta prostrata, Eleusine indica, Emilia sonchifolia, Eriochloa procera, Euphorbia hirta, Euphorbia prostrata, Fimbristylis miliacea, Heliotropium indicum, Ipomoea pes-tigridis, Ipomoea triloba, Leptochloa chinensis, Mimosa pudica, Mimosa sp, Murdannia nudiflora, Paspalum dilatatum, Phyllanthus niruri, Phyllanthus virgatus, Portulaca oleracea, Spilanthes acmella, Synedrella nodiflora, Trianthema portulacastrum, Vernonia cinerea*,

Seed priming resulted in more rapid seedling emergence in the field in all cultivars (Table 20). On average, plants from primed seeds emerged 18.5 h ahead of unprimed sowings.

Table 20. Mean (± s.e.) time to 50% emergence.

Cultivar	Treatment	Time (h) to 50% emergence	
1 IR70213-10-CPA-4-2-3-2	Unprimed	132.9	(2.13)
	Primed	146.0	(23.23)
2 IR68840-57-1-2-2	Unprimed	138.6	(1.57)
	Primed	165.4	(1.61)
3 IR69504-48-SRN-2-UBN-1-2	Unprimed	135.4	(3.00)
	Primed	150.7	(4.00)
4 IR70168-39-PMI-7-B-1-2-3	Unprimed	147.5	(5.43)
	Primed	165.6	(1.65)

There was no effect of priming on row counts at 7 DAE which did not differ amongst cultivars, mean 44 ± 2.5 plants per 1m row. However by 27 DAE, counts were significantly lower ($P < 0.001$) in stands from primed sowings (mean 28.3 ± 1.32) in contrast to unprimed sowings (37.2 ± 2.05). This difference persisted through to harvest. Priming did not effect height extension rate in any cultivar.

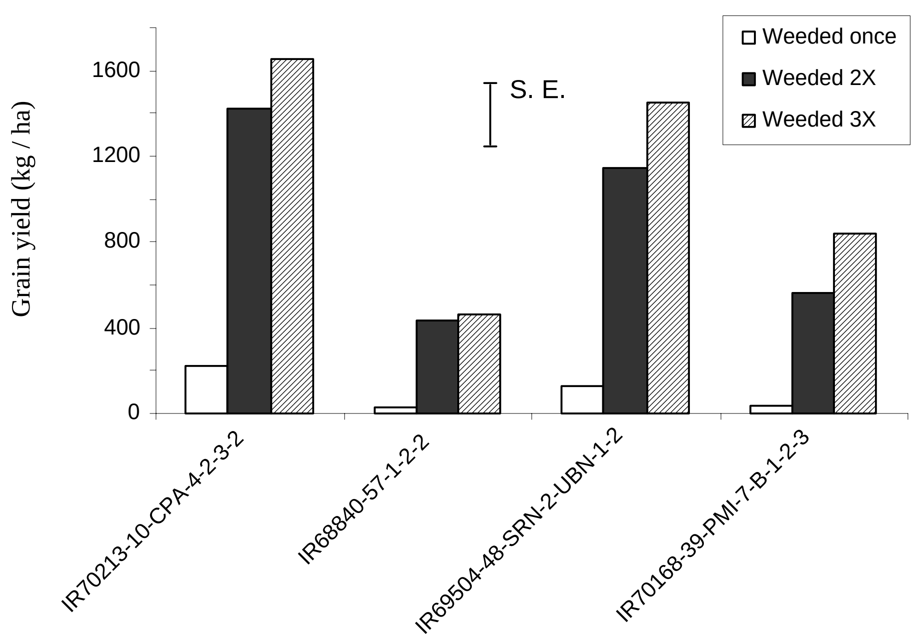
Plant mortality in stands from primed seed led to tiller compensation and by 42 DAE, there was no significant difference in tiller number per 1m row ($P < 0.09$) between priming treatments (mean tiller number 91.2 ± 5.6). Cultivars differed in tillering in response to weeding regimes (Table 21), cv IR68840-57-1-2-2 being the least responsive to the second weeding.

Patterns in rice grain yields reflected the overriding effects of weeding regime, cultivar and their interaction (Table 21, Fig. 9). Cultivars IR 70213-10-CPA-4-2-3-2 and IR69504-48-SRN-2-UBN-1-2 were most responsive to increased weeding whereas little gain was accrued from the third weeding in IR68840-57-1-2-2. There was no significant effect of priming on yield ($P > 0.9$). Other growth traits measured during the course of the experiment indicated differential responses of cultivars to weeding regime (data not shown) but no response to priming.

Table 21. Significant sources of variation in grain yield at harvest and tiller number, 42 DAS.

Source	DF	P Ho	
		Tiller / m^2 42 DAS	Grain yield
Block	2	-	0.0377
Variety (V)	3	-	0.0001
Error(A)	6		
Weeding regime (W)	2	-	0.0001
V*W	6	0.001	0.0005
Error(B)	16		
Priming (P)	1	-	-
V*P	3	-	0.0778
W*P	2	-	-
V*W*P	6	0.049	-
Error(C)	22		

Figure 9. Grain yield at harvest.



4.4.5. EXPERIMENT 4. INVESTIGATION OF THE IMPACT OF PRIMING ON COMPETITIVE INTERACTIONS

Plant populations at two densities (approximating to seed rates of 100 and 200 kg/ha) were established by sowing seeds in rows into large plastic trays (70 x 40 x 20 (deep) cm) containing Maahas soil, with a sterilized surface layer to prevent unwanted weed germination. Thirty-five seeds were sown per row, 4 rows per tray giving a low density stand (500 m^{-2}) and eight rows double this density. Five upland and lowland cultivars were used, seed being either primed or unprimed. A purple leafed rice variety (cv Mashuri) was sown, at a density of 70 plants per tray, at random between the rows as a focal species to measure the intensity of competition from the surrounding rice stand. The sowing depth of all seeds was 5cm. Factorial combinations of treatments were allocated at random in a randomized block design with three replicates. The experiment was conducted in a screenhouse at IRRI, Los Banos during the dry season (April 2000). Trays were carefully watered individually every day to field capacity.

Emerging seedlings were counted twice a day (at 07.00 and 15.00 hrs) until recruitment ceased. The height of a sample of 15 individual plants was taken at 7, 10, 14 and 21 DAS. A single destructive harvest was taken, 21DAE when plant density, height, number of tillers, number of leaves, leaf area and dry biomass per plant were measured.

Seedlings emerged rapidly and cultivars differed in time to 50% emergence (Fig. 10), with no effect of priming or seed rate. Plants from primed seed were taller 7 DAS (Table 22, 23) but this initial difference of approximately 10 mm was lost by 21 DAS. At 21 DAS, cultivars differed in all measured growth traits (Table 22) and the higher seed rate resulted in reduced plant size in all traits. On average, plants from primed seed had higher total biomass than unprimed ones (Fig 11) and this was also reflected in leaf area per plant in eight cultivars (Fig 12). The focal species was differentially suppressed by cultivars in all measured traits and by the higher seeding rate. Priming did not significantly enhance suppression (Fig 13).

Table 22. The influence of priming on height gain. Data are mean height (mm), averaged over all cultivars.

Treatment	7 DAS	10 DAS	14 DAS	21 DAS
Primed	104 ± 2.4	186 ± 3.0	288 ± 4.1	494 ± 6.8
Unprimed	89 ± 1.2	176 ± 2.8	279 ± 4.3	492 ± 6.1

Table 23. Significant sources of variation in means in growth traits of rice and of the focal species as detected by ANOVA. * P < 0.05; ** P < 0.01.

Rice cultivars

		Early Development			Harvest					
Source of variation	DF	Plant Height 7 DAS	Plant Height 10 DAS	Plant Height 14 DAS	Plant Height	Total Dry Biomass per plant	Number of leaves/plant	Leaf Area per plant	Leaf dry wt per plant	Stem dry wt per plant
BLOCK	2			**	*					
CULTIVAR (C)	9	**	**	**	**	**	**	**	**	**
ERROR(A)	18									
SEEDRATE (S)	1					**	**	**	**	**
C x S	9				*					
ERROR(B)	20									
PRIMING (P)	1	**	**	**		**		**		
C x P	9									
S x P	1							*		
C x S x P	9									
ERROR (C)	40									

Focal species

		Early Development			Harvest					
Sources of variation	DF	Plant Height 7 DAS	Plant Height 10 DAS	Plant Height 14 DAS	Plant Height	Total Dry Biomass per plant	Number of leaves/plant	Leaf Area per plant	Leaf dry wt per plant	Stem dry wt per plant
BLOCK	2		*	**						
CULTIVAR (C)	9				**	**	**	**	**	**
ERROR(A)	18									
SEEDRATE (S)	1			**	**	**	**	**	**	**
C x S	9		*	**						
ERROR(B)	20									
PRIMING (P)	1									
C x P	9									
S x P	1									
C x S x P	9									
ERROR (C)	40									

Figure 10. Time of emergence in relation to priming and seeding rate in ten cultivars. Reading from the left, the first set of five are upland and the second set lowland cultivars.

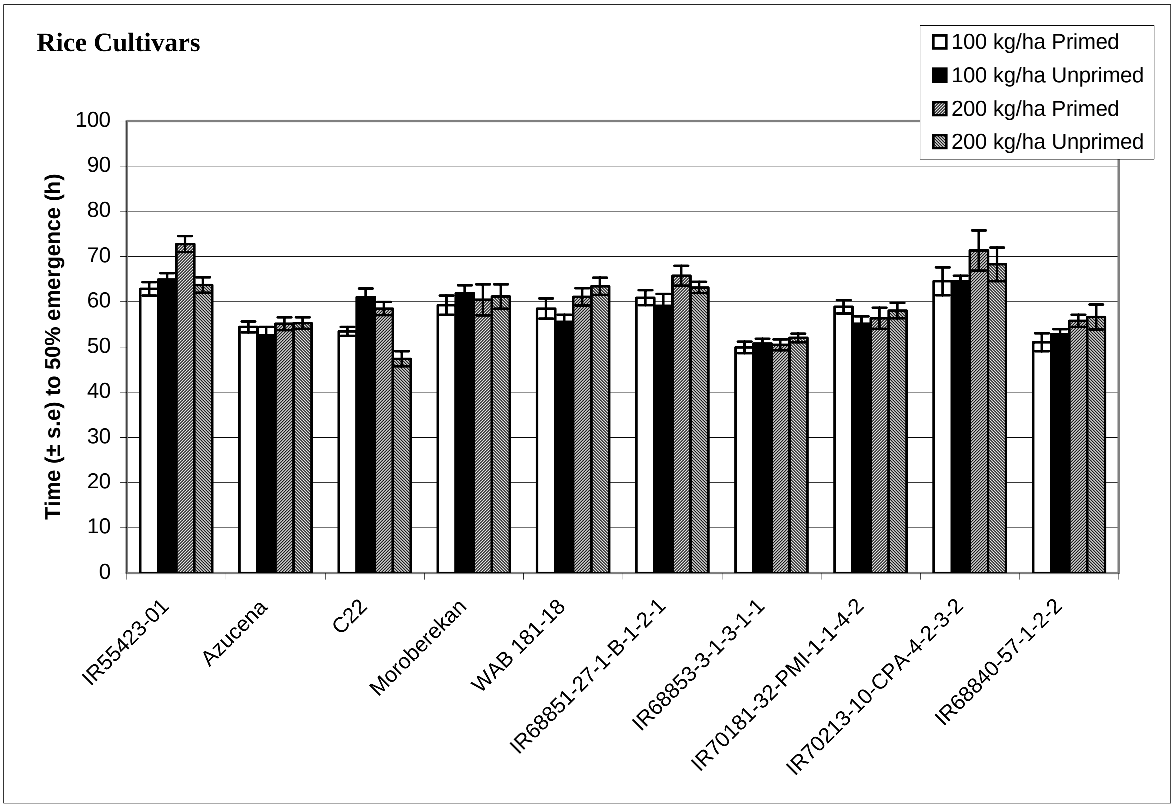


Figure 11. Plant biomass in relation to priming and seeding rate in ten cultivars.

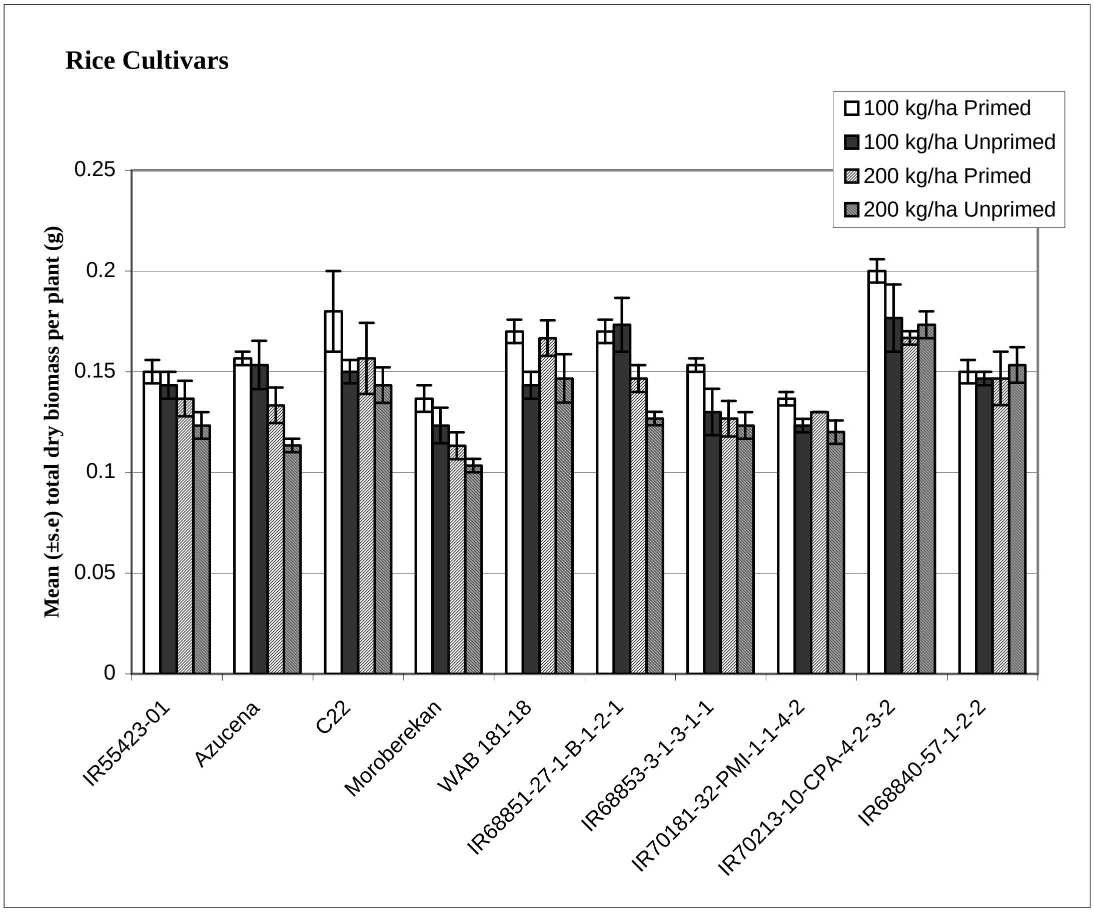


Figure 12. Plant biomass in the focal species in relation to companion cultivar, priming and seeding rate.

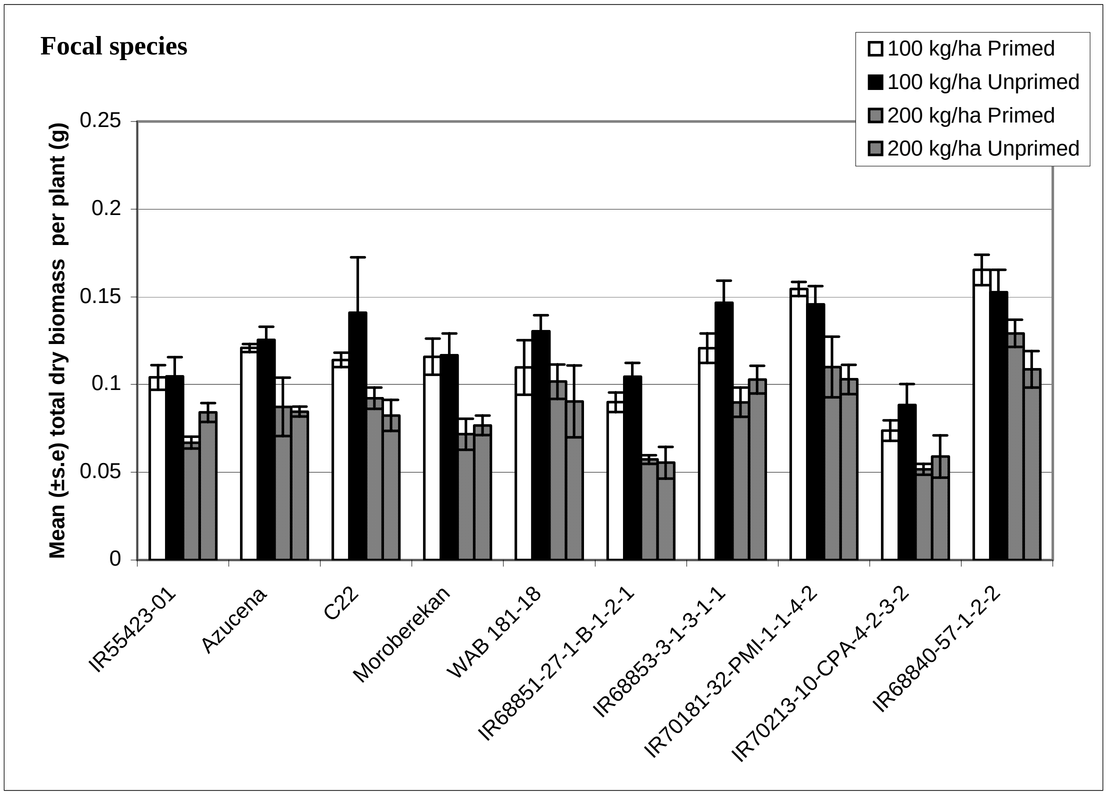
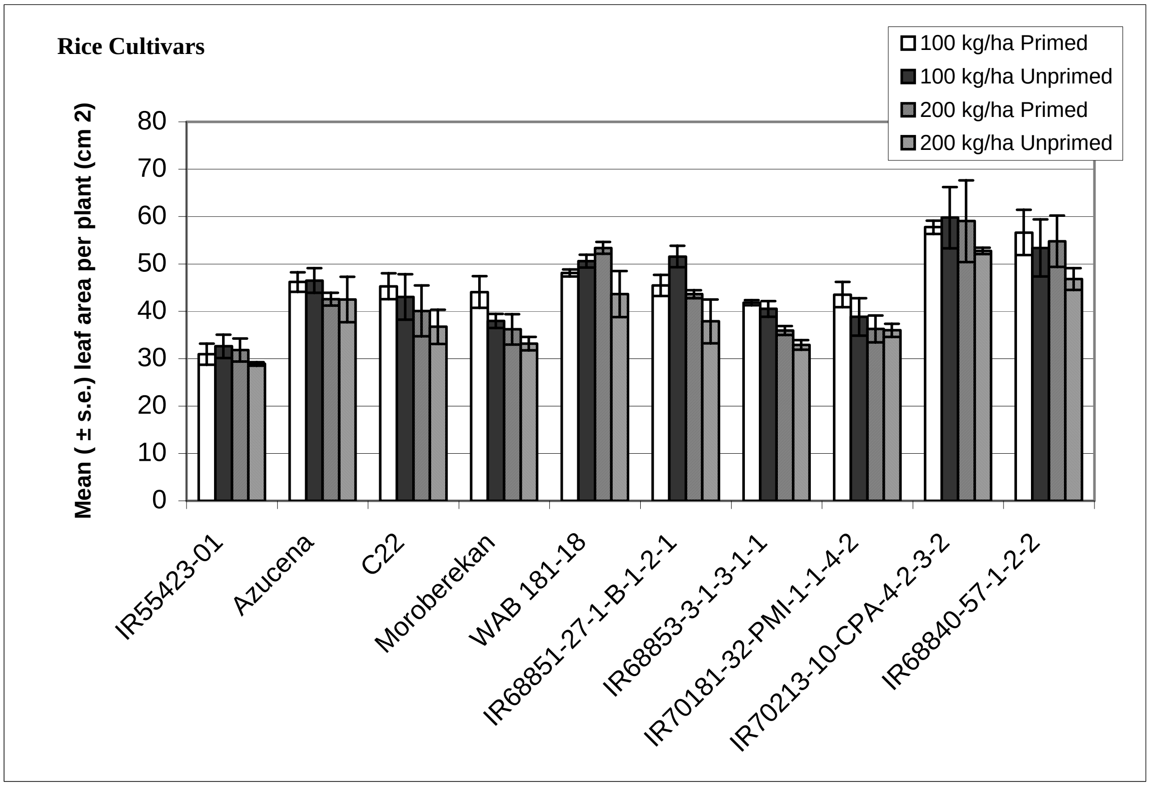


Figure 13. Leaf area per plant of rice cultivars in response to priming and seed rate.



4.4.6. EXPERIMENT 5. ASSESMENT OF RESPONSES TO PRIMING IN THAI UPLAND RICE CULTIVARS

Materials and Methods

An on-station field trial was conducted from June – August 2000 at the Samoerang Upland Rice and Temperate Cereal Crop Experiment Station, Chiang Mai, Thailand. The performance of 10 upland rice cultivars in common use was examined in stands established from primed and unprimed seeds, in the absence and presence of weeds. A factorial combination of treatments was used in a randomized complete block design with three replicates. Individual plots were 2 m square and rice hand sown at a depth of 4cm in rows 25cm apart at a rate of 50 kg/ha. Weed free plots were manually weeded every 10 days after rice emergence. A single manual weeding (10 DAS) was applied to weedy plots to prevent excessive competition, thereafter they were unweeded and a diverse flora of weeds typical of Asian upland rice developed. The soil was a free draining sandy loam, and plots had previously been in dry season fallow. Rice cultivars were : Ble Chai, Jao Haw, Jao Khao , Jao Li Saw, Khao Daeng Hawm, Khao Pong Krai, Nam Roo, R258, Sewdaeng and Sew Mae Jan. All cultivars with the exception of R258 are traditional cultivars.

Rice stand counts were taken 7 and 14 DAS in two randomly chosen 50cm row lengths in each plot, together with height measurements at 7, 14, 21, 28 and 35 DAE on a random sample of 10 plants. Rice dry biomass was measured at 50 DAE in the central 1m square when tillering had ceased. Weed biomass was sampled at each time of weeding and at harvest.

Table 24 summarises significant sources of variation in cultivar response to priming and weed treatments. Row counts (14 DAS) varied noticeably amongst cultivars with reduced stands occurring in cvs Khao Daeng Hawm and R258. Priming of seed increased row counts in nine cultivars and most noticeably (8 plants or more) in seven cases (Table 25). Overall, plants from primed seed were taller 14 DAS (Table 26) and cultivars showed a differential response to priming in height extension rate (data not shown) during early plant growth. Differences in height were absent by 35 DAS. The response to weed competition in eight cultivars was to increase plant height (by 4 – 8cm), cv Jao Khao being unresponsive and cv Sew Mae Jan showing reduced height (4.5cm) in the presence of weeds

Priming significantly increased dry plant biomass m^{-2} at harvest 50 DAE. Figure 14 shows the relationship between yield in weed free plots (ordinate) and yield under weed competition (abscissa) for primed and unprimed cultivars. Cultivars falling to the left of the unit line suffered yield loss from competition from weeds. When unprimed, cv Jao Haw and Sew Mae Jan were most sensitive to competition and cv Nam Roo was the most productive and showed little suppression from weed competition. In all cultivars, the mean yield from primed seed was elevated over the yield from unprimed seed but in only Jao Li Saw and Sewdaeng were significant differences detected ($P < 0.05$). Priming did however alter the relative ranking of sensitivity to weed competition (Table 27), on the basis of biomass per unit area (50 DAE). The response to priming in Sewdaeng was to increase yield in both weed free and weedy plots, whereas in Jao Li Saw the response was only seen in the absence of weeds.

Table 24. Analysis of variance and significant sources of variation for row counts, plant height and biomass.

Source	DF	Row count	Plant height at 35 DAS	Biomass m^{-2} 50 DAS
Block	2	0.006	-	0.061
Cultivar (Var)	9	0.001	0.027	0.0001
Priming (Tmt)	1	0.001	0.006	0.0001
Var*Tmt	9	-	0.016	-
Weed	1	-	-	0.001
Var*Weed	9	-	0.007	-
Tmt*Weed	1	-	-	-
Var*Tmt*Weed	9	-	0.038	-
Error	78		-	

Table 25. The effect of priming on initial establishment. Data are the mean number of plants per 1m row, 14 DAS. S.E = 6.4.

Cultivar	Treatment	Mean number of plants
Ble Chai	Primed	88.1
	Unprimed	58.8
Jao Haw	Primed	63.6
	Unprimed	45.1
Jao Khao	Primed	38.0
	Unprimed	26.8
Jao Li Saw	Primed	55.3
	Unprimed	47.3
Khao Daeng Hawm	Primed	22.5
	Unprimed	12.6
Khao Pong Krai	Primed	30.3
	Unprimed	22.3
Namroo	Primed	60.6
	Unprimed	64.8
R258	Primed	18.8
	Unprimed	12.1
Sewdaeng	Primed	59.1
	Unprimed	56.1
Sew Mae Jan	Primed	65.3
	Unprimed	54.3

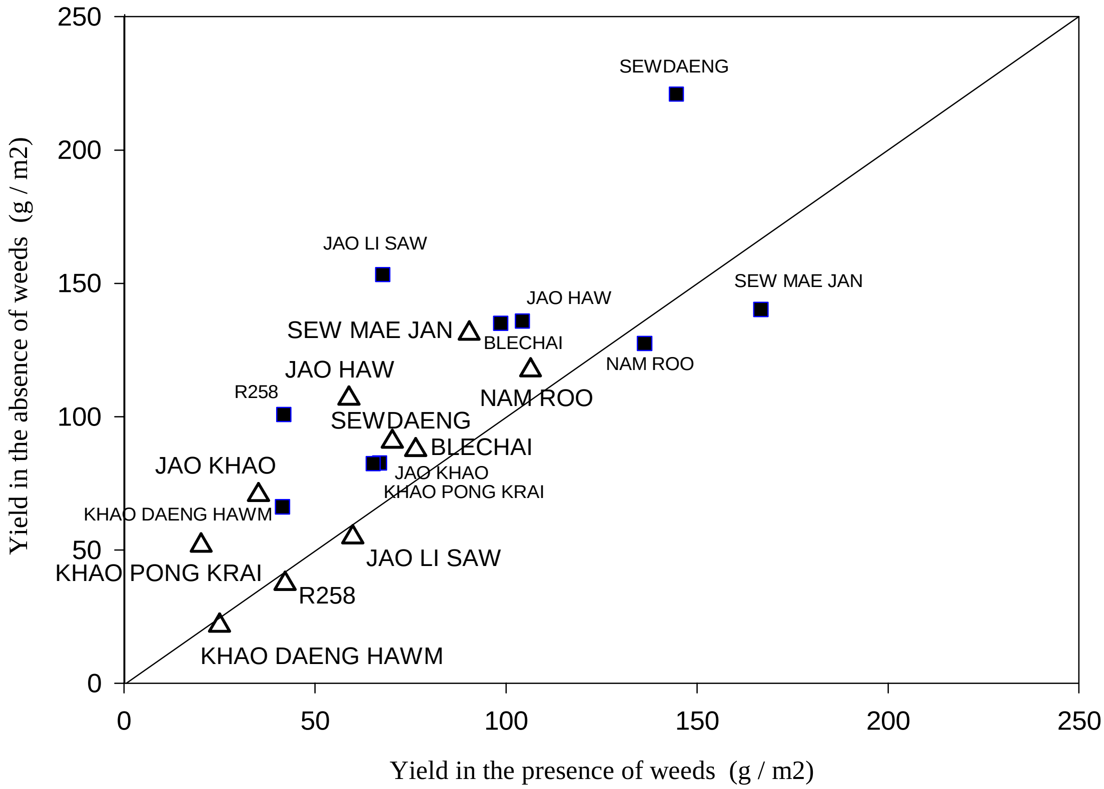
Table 26. The effect of priming on plant height. Data are mean (± s.e.) plant height (mm).

Treatment	14 DAS	21 DAS	28 DAS	35 DAS
Primed	220 ± 5	350 ± 6	480 ± 12	68 ± 70
Unprimed	180 ± 4	310 ± 7	430 ± 10	66 ± 60

Table 27. The sensitivity (log response ratio, R, Goldberg *et al.*, 1999) of cultivars to competition from the weed flora. High values indicate greater sensitivity.

Primed		Unprimed	
Sew Mae Jan	-0.17	Khao Daeng Hawm	-0.16
Nam Roo	-0.06	R258	-0.13
Jao Khao	0.22	Jao Li Saw	-0.09
Khao Pong Krai	0.23	Nam Roo	0.09
Jao Haw	0.26	Ble Chai	0.12
Ble Chai	0.31	Sewdaeng	0.22
Sewdaeng	0.42	Sew Mae Jan	0.31
Khao Daeng Hawm	0.47	Jao Haw	0.44
Jao Li Saw	0.82	Jao Khao	0.50
R258	0.88	Khao Pong Krai	0.61

Figure 14. Yield relationships in relation to weed competition and priming for 10 cultivars. Yield is total plant biomass, 50DAE. Primed seed : squares, small text; Unprimed seed: triangles, large text. S.E. = 22.6 (g / m^2).



4.4.7 Discussion

This series of experiments indicated that seed priming strongly influenced the germination rate of rice in controlled laboratory conditions. In contrast to previously reported methodology, seeds were primed by a 48 h cycle of wetting and drying. This proved superior to soaking alone in three cultivars and this observation has been confirmed by independent studies at IRRI (T.Tuong, per comms). One simple explanatory mechanism is that changes in the structural integrity of the lemma and palea (hull) and scutellum occurred through wetting and drying and this improved imbibition of water when freely supplied. Across the genotypes considered, this priming process improved the germination rate to the greatest extent in cultivars adapted for upland cultivation in aerobic soils.

Under field conditions, the rate of seedling emergence was fastest from primed seeds (Expts 3 and 5). However this response was not observed in a soil moisture regime maintained at field capacity (Expt 4) even though very frequent observations were taken and a range of cultivars was examined. Nevertheless in this experiment, differences due to priming were evident in plant height, 7 DAS. Although not measured experimentally, soil aeration will have differed due to watering regimes between Expts 3 and 4, in which three cultivars were in common. Physiological and morphological processes effecting relative development of mesocotyl, coleoptile and coleorhiza and roots are known to be responsive to different mosture regimes (Takahashi, 1978). In Expt 4 it is possible that a predominantly anaerobic soil promoted rapid coleoptile extension overriding or delaying other developmental processes which would otherwise have led to varietal differences. Variation in mesocotyl extension is reported to occur in both *indica* (5 – 80mm) and *japonica* rices (2-5mm with a maximum of 50mm) being cultivar and environment dependent (Hoshikawa, 1993). The role that priming has in governing germination rate and subsequent expression of mesocotyly extension and associated risks of successful establishment deserves further investigation. In turn, this may influence expression of plant height in early growth which was increased by priming in Expt 4 (screenhouse) and Expt 5 (on station, upland cultivars). Typically, the first leaf primordium in rice starts growing before the coleoptile achieves full length and improved water uptake as a result of changes in permeability of the seed coat will enhance resource mobilization and ontogeny.

Faster early growth rate from priming may confer phenological advancement and improved resource capture leading to increased yield as well as superiority in competition with weeds. In Expt 3 (on-station IRRI) yield increases were not detected although there were noticeable differences amongst cultivars in their response to weeding regimes and in tillering capacity. Differential cultivar responses were also detected amongst upland rice cultivars in Thailand (Expt 5) in which priming increased total plant biomass at the maximum tillering stage. In this trial, cultivar sensitivity to competition from a background weed flora was influenced by priming in several cultivars. However the underlying dynamics of this process in terms of tillering rate, specific leaf area and leaf and stem area distribution were not examined in this trial and point to the need for further study to explore the mechanisms underlying weed suppression.

From these empirical studies it is concluded that whilst seed priming enhances germination rate, translation of potential positive gains in subsequent earlier growth and development are strongly dependent upon soil environment and the innate yielding ability of cultivars. It will be only through improved understanding of cultivar yield potential and competitiveness that the magnitude of the effects and reliability of seed priming can be fully understood.

4.5. Seed priming as a component of integrated weed management in upland rice, West Africa[7]

On-farm seed priming, that is soaking seed for periods of up to 36 hours before drying and sowing, has been proposed as a simple technology for improving stand establishment and promoting seedling vigour in rainfed agriculture (Harris *et al*., 1999). It has been suggested that since rapid stand establishment and vigorous early plant growth are important components of weed competitiveness in upland rice crops a related benefit of seed priming may be increased crop competitiveness (Harris and Jones, 1997). Harris *et al*., (1999) have demonstrated faster germination rates in primed rice seed. In the same study farmers in India reported seedling emergence advanced by 2-3 days and positive effects on plant vigour, as well as earlier flowering and maturation in primed crops. Singh and Chatterjie (1981) report increases in plant population, leaf area, root growth and yield in primed upland rice in India. One concern surrounding the seed priming is the potentially negative effect of delayed sowing. Short (24 hour) delays in sowing primed seed have been shown to have no negative effects; germination rates were reduced but remained faster than that of unprimed seed (Harris *et al.*, 1999). The effects of priming rice seed on germination, emergence and crop competitivity were investigated in a series of experiments carried out at WARDA's research station, M'be Cote d'Ivoire between 1999 and 2000.

4.5.1. Experiment 1, Effect of priming on rice growth and development

The experiment was sited on an upland field at WARDA's research farm at M'be (5' 06 W 7' 52N, 300m asl) Côte d'Ivoire. The trial took place during the dry season; sowing dates were 29 January and 25 February 1999. Overhead irrigation was used to supplement rainfall. Five rice varieties were tested under three seed priming treatments: 1. Control, no soaking; 2. Soaked for 12 hours, surface dried and sown; 3. Soaked for 24 hours, surface dried and sown. Seeds were sown at a rate of 5g per a single test line of 1.5 m, with 1m between rows. No herbicides or fertilisers were applied. Emergence was recorded daily from 20cm within row up to 13 days after sowing. At 21 and 28 days after sowing the number of plants and tillers from 50cm within the central test row was recorded. At 28 days plant height was recorded for 10 plants. The experiment was terminated at 28 days when the above ground biomass was harvested from 1m within the row. The experiment was laid out as a randomised complete block with three replicates. Rice varieties were IG10 (*Oryza glaberrima*); Moroberekan (*O. sativa*) and inter-specific cultivars WAB450-I-B-P-129-HB; WAB450-I-B-P-126HB and WAB450-11-1-1-P50-HB.

Seedling emergence was highest and more rapid in seed soaked for 24 hours. Seed soaked for 12 hours showed a faster emergence rate than non-primed seed but no overall increase in final emergence (Figure 15). Across varieties plant number was higher at 28 days in seed soaked for 24 hours than for non-primed seed (Table 28), but this effect is not apparent in all varieties. Plant biomass at 28 days was significantly lower in seed that had been primed for 12 hours than seed that had not been primed and there was no difference between seed that had not been primed compared to that which had been soaked for 24 hours.

[7] Contributed by Dr D. Johnson

Table 28. Plant number and height; tiller number and dry weight at 28 days of 5 rice varieties at 3 seed treatments, means of 2 experiments.

	Plant no. m^{-1}			Tiller no. m^{-1}			Plant ht cm			dry wt gm^{-1}		
Soaking time (hrs)	0	12	24	0	12	24	0	12	24	0	12	24
IG10	78	70	100	57.0	62.0	95.0	24.9	24.1	27.9	8.92	8.25	13.42
Moro	60	52	56	12.4	6.4	9.6	32.3	31.3	30.6	8.63	6.27	7.64
WAB-129	68	60	58	15.6	19.6	22.6	32.1	32.9	33.3	9.98	9.32	9.94
WAB-126	52	36	64	39.6	20.4	27.4	32.3	29.0	30.1	11.54	6.74	9.70
WAB-P50	50	62	72	29.0	17.3	15.6	29.2	26.7	26.1	6.98	6.55	7.62
se			± 10.0			± 7.44			± 1.2			± 1.33
Mean	61	56	70	30.8	25.2	34.0	30.1	28.8	29.6	9.20	7.43	9.66
se			± 4.5			± 3.32			± 0.54			± 0.60
CV			39.2%			60.8 %			10.0 %			39.3 %

4.5.2. Experiment 2. Growth of primed and un-primed rice in the screenhouse

A pot trial was undertaken in the screenhouse at M'be in June and October 2000. 50 seeds were sown per pot (2.5 l) filled with an upland soil from the research farm. Two priming treatments were 1. Soaked for 24hrs, air dried and sown; and 2. Not soaked. 10 varieties were used. The pots were arranged in a complete randomised block design with 3 replicates. Emergence was counted at 3, 5, 7 and 10 days after sowing. At 10 days each pot was thinned to 10 plants. At 21 and 28 days leaf and tiller number were counted. At 28 days plants were harvested and above ground biomass (dry weight) recorded. In the second run counts at 3, 7 and 21 days were not possible. Varieties tested were IG10, Moroberekan, Suakoko, WAB56-104 (*O. sativa*) and inter-specific cultivars WAB450-I-BP-129-HB, WAB450-11-1-P31-1-HB, WAB189-B-B-B-8-HB, WAB450-I-B-P-102-HB, WAB450-8-3-3-MB-HB, and WAB450-I-B-P-82-1-19.

Seedling emergence was faster in primed seed. However, with the exception of two varieties the final emergence at 10 days was not significantly higher in primed seed and in IG10 was significantly lower. Plant biomass and number of leaves per plant at 28 days were consistently higher in primed than in non-primed seed (Table 29).

Table 29. Experiment 2. Emergence at 5 and 10 days, mean number of leaves per plant and dry weight at 28 days (ANOVA).

	no. of plants at 5 days		no. of plants at 10 days		Mean no. of leaves per plant at 28 days		dry weight of 10 plants at 28 days	
	P	NP	P	NP	P	NP	P	NP
IG10	38.8	40.3	40.3	45.5	4.8	4.5	1.09	1.01
moroberekan	26.5	20.7	29.5	28.0	4.5	4.2	0.96	0.78
suakoko	44.3	41.0	44.2	46.5	5.0	4.9	0.93	0.80
WAB450-I-BP-129-HB	35.7	28.2	37.8	34.0	4.0	3.9	1.06	0.93
WAB450-11-1-p31-1-HB	43.8	40.0	46.5	47.0	4.1	3.9	0.78	0.69
WAB189-B-B-B-8-HB	38.8	26.5	40.8	39.8	4.2	4.1	0.88	0.75
WAB450-I-B-P-102-HB	26.0	20.3	28.0	26.3	4.1	4.0	0.94	0.74
WAB450-I-B-P-82-1-19	32.7	29.3	33.7	33.5	4.1	4.0	1.03	0.88
WAB56-104	44.7	39.3	46.7	43.0	4.0	3.9	0.89	0.78
se		±1.51		±1.56		±0.06		±0.042
mean	36.8	31.7	38.6	38.2	4.3	4.1	0.95	0.82
se	**	±0.50	ns	±0.52	**	±0.02	**	±0.014
cv %		10.7		9.95		3.77		11.62

4.5..3. Experiment 3 Germination of primed seed after storage

Five varieties of seed received two priming treatments 1. Soaking for 24 hours and then air-dried; 2. Not treated. Every 2 days, up until 64 days after soaking, 50 seeds were removed for germination tests. A final germination test was carried out at 84 days. Varieties were cultivars Bouake 189; Gambiaka; WAB 56-50; Moroberekan (all *O. sativa*); and CG14 (*O. glaberrima*).

Across cultivars priming seed initially increased germination, but this advantage subsequently declined and from 27 days onwards priming had a negative effect on viability (Figure 16). There were significant differences in slope between varieties ($P<0.0001$). Seed priming showed little or no improvement in germination in CG14 and the regression indicates a negative effect after 12 days, while in Bouake 189 the initial effect was greater and was lost after 30 days (Figure 17).

4.5.4. Experiment 4. Effect of priming on competitiveness of upland rice with weeds.

The experiment was sited on an upland field at M'be and comprised three replicates of a completely randomised block design with 10 varieties and two priming treatments. Each plot (0.75m x 2m) contained five rows of rice. Two 'competitor' rows of the test variety were sown outside a central row of WAB 56

104, a cultivar very sensitive to competition, these were bordered by a row of Moroberekan on either side. Two priming treatments were included 1. Not primed, 2. Soaked for 24 hours, air dried and sown. Seed was sown at a rate of 5g per 2m line. The site received a basal P application of 20kgP/ha as TSP. Nitrogen was applied as urea at a rate of 46kg N/ha split equally at 28 and 56 days. Pre-emergence herbicide, oxadiazon at 0.75kga.i. /ha, was applied to all parcels one day after sowing. Data collected from the central line (WAB 56 104) and the variety test lines: counts of tiller number from 0.5m within row at 21, 35 and 49 DAE; height of 5 plants at 56 DAE; above ground biomass from 50cm within row at 56 DAE; above ground biomass at harvest from 1 m; counts of panicles from 1m within row; grain weight.

Table 30. Experiment 4. Plant number and yield rice in central and competitor (test) rows (means of 10 varieties). Yield values are adjusted for plant number.

			plants / m			panicles/m	grain g/m	straw g/m
			21 days	35 days	49 days			
1999	WAB56-104	P	80.4	70.2	-	54.6 *	55.0 **	61.4 *
		NP	80	66.2	-	46.5	40.1	54.1
	CV%		20.6	23.6	-	27.9	34.9	22.46
	se		3.01	2.94	-	2.60	3.06	2.40
	Test lines	P	64.3 *	57.4 **	59.7	50.3 *	56.4 **	74.3 *
		NP	70.6	65.0	64.3	46.6	47.9	63.0
	CV%		17.2	16.4	21.6	14.4	21.3	24.7
	se		2.16	1.83	2.45	1.29	2.06	3.14
2000	WAB56-104	P	56.8	50.6	44.0	54.4	41.1	48.65
		NP	61.4	50.8	43.0	57.4	43.7	51.0
	CV%		25.5	25.5	22.7	17.1	29.3	17.13
	se		2.75	2.36	1.80	1.74	2.24	1.56
	Test lines	P	53.4 **	43.6 *	43.6 **	48.4	37.0	60.3
		NP	66.2	49.0	53.2	49.5	34.9	55.0
	CV%		23.7	22.3	19.9	12.79	31.2	31.8
	se		2.59	1.88	1.76	1.15	2.05	3.4

In 1999 the results indicate a higher grain yield in the competitor rows (test varieties) that were primed and also in the central row of WAB56-104 in primed treatments. These results were not repeated in 2000 when priming was found to have no significant effect on yield of either the central or competitor lines (Table 30). In both years seed priming had a detrimental effect on plant number in early growth stages (Table 30). The effect on the central line (WAB56-104) of priming the competitor lines in 1999 may be due to the lower density of plants in competitor lines that received the priming treatment. A lower plant number in competitor lines could be expected to reduce competition for the central lines resulting in increased growth. In 1999 grain yield in WAB56-104 was found to be negatively correlated to tillering in border lines at 49 days (r=-0.272, P>0.05). Plant number in the border lines of the varieties IG10 and Moroberekan was negatively correlated to grain yield in WAB56-104 (-0.746 and -0.766 respectively).

4.5.5. On farm testing of seed priming - humid forest zone, Côte d'Ivoire

More rapid seedling emergence and improved plant stand is likely to lead to improved suppression of weeds and better yields under upland conditions. One means of achieving this under low input conditions is to prime the seeds before sowing. Experiments on station in the Côte d'Ivoire in 1998/99 showed that priming rice seed by soaking for 24 hours before sowing led to more rapid seedling emergence and c. 10% increase in the number of established seedlings. Similar advantages were found in on-farm testing in Nigeria in the same year.

Seed priming was tested in the 2000 wet season by incorporating primed seed into the on farm varietal testing. Plots of rice that have been primed and unprimed will be superimposed on farmers' fields.

Treatments:
With the 4 varieties being used for on farm testing + farmers' own, seeds will be sown (25 g per plot). The varieties were: 1.) WAB 189 - BBB - 8 - HB, 2.) WAB 488 - 161 - 2, 3. WAB 450 - I - B - P 91 - HB, 4.) IDSA 78, 5.) Local variety

These were either:

1. unprimed
2. primed for 24 hrs (soaked in water for 24 hrs before sowing, surface dried and sown)

Plots size was 2 m x 2m, one complete replicate on each of 20 farms. All other crop management and inputs will be as per the farmers normal practice.

Data recorded:

Emergence at 14 DAE - number of rice seedlings in 1 m^{-2} quadrat
Score the weeds at 21 DAS as % ground cover in 1 m^{-2} quadrat
Weigh the weeds at harvest - in 1 m^{-2} quadrat.

Rice tiller and panicle number at harvest (10 plants at random)
Rice yield at harvest (1 m^{-2} at harvest)

There were differences among the five varieties, across the priming treatments, in the early plant stand, grain yield and weed growth (Table 31). The local variety recorded the lowest plant stand that was the probable cause of the lower yield and the highest weed growth recorded at harvest. There were no significant effects of priming on the variables recorded.

Table 31. Growth of five rice varieties with and without priming, on 20 farm sites in the humid forest zone. Wet season 2000.

	Emergence plants m^{-2}	Tillers nos plt	Weeds g m^{-2}	Yield g m^{-2}
WAB 189 - BBB - 8 – HB	73.4	4.73	637	213
WAB 488 - 161 -	79.4	4.58	558	211
WAB 450 - I - B - P 91 – HB	80.2	4.53	568	205
IDSA 78	87.3	4.70	548	243
Local	62.8	4.45	869	200
SED	3.16	ns (0.117)	42.3	10.1
Unprimed	77.4	4.69	620	208
Primed	75.9	4.50	652	220
SED	ns (2.00)	ns (0.074)	ns(26.7)	ns(6.4)

4.5.6. CONCLUSIONS

In concurrence with other studies, the present research indicates more rapid seedling emergence in primed seed. However, the effect of priming on final emergence is not clear and in some cases was reduced in primed seeds. The effect of priming differed between varieties, both in the impact on germination and the long-term viability of seed following soaking and drying. The factors that were studied in these experiments do not allow conclusions to be drawn on the variable responses to seed priming observed, however seedbed conditions, weather and the physiological state of seed may be important elements. The results of these experiments suggest that until the reasons for this variability can be resolved, any promotion of this method should be based on local field tests to ensure that priming is not detrimental in the varieties used and conditions prevailing.

Figure 15. Experiment 1. Seedling emergence for primed and non-primed seed (means of 3 repetitions, all varieties, bars are standard errors).

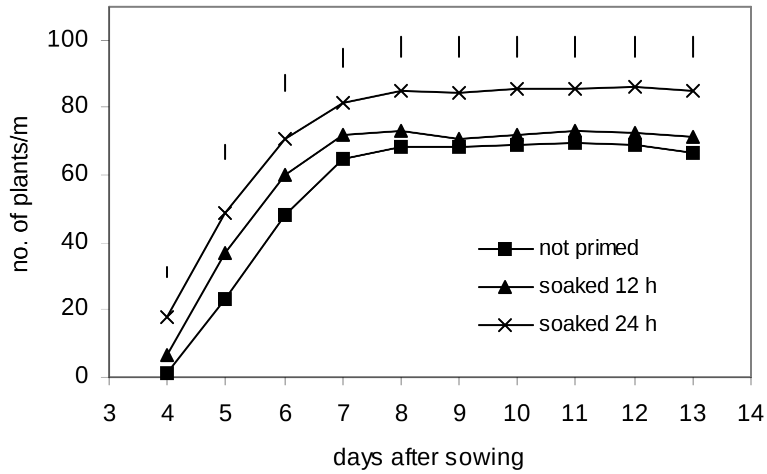


Figure 16. Relative germination (primed/non-primed) over time, mean of all varieties.

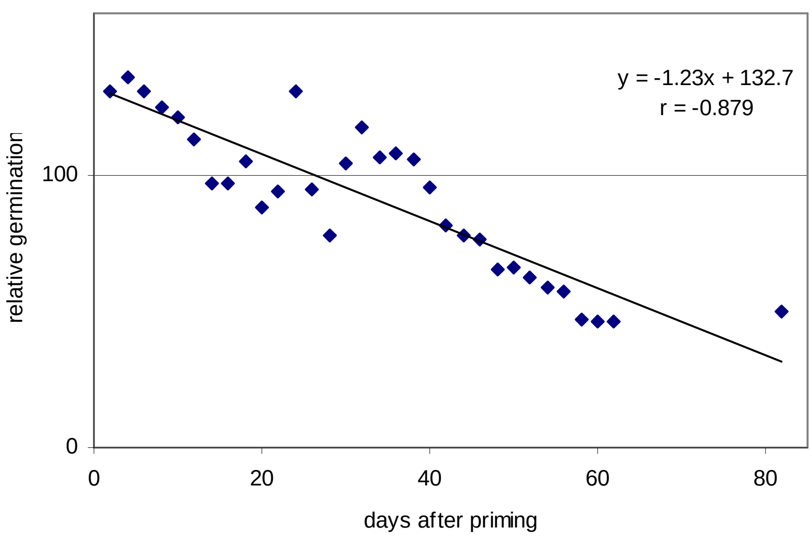
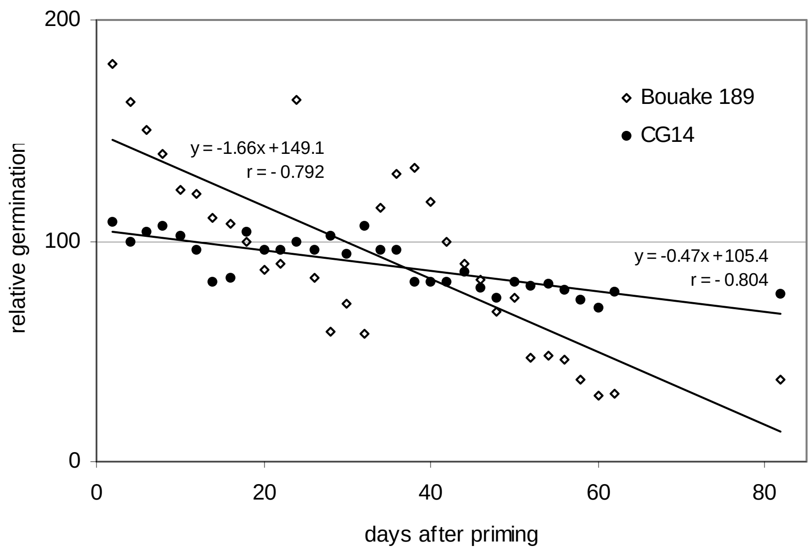


Figure 17. Relative germination rate (primed/non-primed seed) over time comparison of two rice varieties



4.6. Studies on the effect of priming on lowland rice growth in Bangladesh

Studies undertaken in upland rice in India and with chickpeas in Bangladesh have indicated that Seed Priming i.e. soaking seed for 12 hours in water prior to planting may result in the following advantages:

1. Priming improves crop emergence and final crop stand under direct seeding;
2. Priming may result in earlier rice maturity and harvest. If this is the case, the earlier harvest of a primed rice crop may allow timely planting of a rabi crop such as chickpea. A trial was initiated in the 2000 *aman* season at Rajabari, Bangladesh to test these assumptions in direct seeded lowland, rainfed rice.

Seed of primed or un-primed rice, cultivar BRRIdhan 39, was direct seeded at a rate of 50 kg ha^{-1} (dry seed) into two seed bed conditions, "dry bed" and "wet bed" at a highland position on the toposequence. The site initially cross ploughed on 28/29th June. The intention had been to plant the "dry bed" as moist soil at the start of the monsoon. However, the first rains resulted in ponded water. The "dry bed" was therefore ploughed again on 4th July as the soil drained and planted the following day. The "wet bed" was subsequently re-ploughed on 11th July with seed sown the following day into saturated soil. Data were collected on plant stand, tiller number, rice plant height, phenology, panicle number and yield.

Priming resulted in improved stand establishment, tiller number at booting and panicle number on both dry and wet beds (Table 32). Although higher grain yield were harvested from primed plots the difference was not statistically significant. On the dry bed however, priming did lead to significantly higher straw yield. Priming also influenced time to 50% flowering and maturity. This advance in phenology of 1-2 days seems to reflect the earlier emergence of plants developing from primed seed. No additional growth advantage occurred. At this site and in this season therefore, priming did not advance crop maturity to allow earlier chickpea planting. The trial indicated that while priming may have a role to play in improved stand establishment, no increase in yield resulted. It is being repeated during the 2001 season to confirm these findings.

Table 32. The effect of pre-planting seed priming on the growth and yield of direct seeded *T-aman* rice cv BRRIdhan 39.

	DRY BED		WET BED	
	PRIMED	UN-PRIMED	PRIMED	UNPRIMED
Plants m^2 at 14 days	247	197^{*}	225	156^{*}
Tillers m^2 at booting	452	415^{*}	455	390^{*}
Plant ht cm at booting	104	100^{NS}	110	108^{NS}
50% flowering-days	86.5	88.5^{*}	84.8	86.2^{*}
Maturity-days	108.2	109.5^{*}	107.5	108.5^{NS}
Panicle number m^2	338	283^{**}	300	281^{*}
Grain yield kg ha^{-1}	2762	2310^{NS}	3621	3530^{NS}
Straw yield kg ha^{-1}	6102	4804^{***}	7190	6690^{NS}

Note: Significance levels based on T-test with 3 df

5.0 CONTRIBUTION OF OUTPUTS

5.1 Contribution of outputs to project goal

CPP funded this work as a cross-cutting project and the project goal was set as "Selection, delivery and impact of CPP and research projects facilitated through implementation of cross-cutting research applicable across CPP production systems". The project undertook work on maize for semi-arid systems and on rice for upland and lowland production systems in W. Africa and Asia. The project has contributed to the proposed outputs as stated in the log-frames in the following ways.

Output 1. Understanding the role of genotype, seed priming and their interaction on early establishment, seedling vigour and subsequent competitiveness of rice to weeds in upland and lowland ecologies: Work was undertaken on this output at WARDA and IRRI. A series of trials in the screenhouse and field has increased our understanding of the effect of priming on the early growth and weed competitiveness of a range of rice genotypes. Seed priming enhanced biomass yield in upland rice in Thailand but conversely no effects were observed in rainfed lowland rice in the dry season in the Philippines when grain yields were measured. Comparative studies of early growth and tillering in rice cultivars and of weed suppression, suggest that a fuller understanding of the potential benefits of seed priming in rice will come through improved understanding of environmental factors governing cultivar performance.

Output 2. Evaluation of the farmer's perception and likely adoption of seed priming of rice as a component of weed management. WARDA included seed-priming in Participatory Varietal Selection trials in Cote d'Ivoire. However, in the set of on-farm trials completed priming had no effect on plant stand or yield so there was no basis for discussion with farmers. Effects of priming were inconsistent in on-station trials also at WARDA.

Output 3. Understanding the role of genotype, seed priming and their interaction on early establishment, seedling vigour and subsequent competitiveness of maize to weeds in semi-arid systems: Trails were completed at two research station sites over three seasons to evaluate the possible role of maize genotype in competitiveness with weeds in Zimbabwe. No variability was identified in competitiveness with or tolerance to weeds despite previous reports. Information has been generated on the yields on maize hybrids under weed competition, including the lines currently available to farmers. Weed tolerance is a trait which has not previously been considered but it appears that among the hybrids currently on the market are those which produce good yields when weeding is delayed, even under the variable rainfall conditions of Masvingo Province. Priming is being promoted widely as a "key technology" in a number of crops, to ensure good emergence and adequate stands. This project has looked in detail at the possible implications of priming for crop weed tolerance but has concluded that while priming may in some conditions increase crop yield it does not increase competitiveness of maize with weeds *per se*.

Output 4. Evaluation of the farmer's perception and likely adoption of seed priming of maize as a component of weed management in a semi-arid maize based system: Considerable resources were committed to the participatory evaluation of seed-priming with farmers over a two year period in Zimbabwe. In addition to significant yield increases following seed soaking, farmers have indicated a number of other advantages for the practice, including a perception that primed crops are more vigorous and therefore more tolerant of weeds. The on-farm trials work has led to a detailed understanding of farmers' perceptions of priming and has identified the issues which need to be discussed with farmers when the practice in promoted.

5.2. Follow-up action to promote findings

Although effects of priming on maize yields have been inconsistent, there has been sufficient interest and demand for more widespread demonstration and testing of the technique from farmers in southern Zimbabwe. Demonstrations of priming and development of associated promotional information have therefore been included within activities outlined in the concept note "Promoting improved crop establishment and weed management of toplands and wetlands in semi-arid areas of Zimbabwe". This was submitted to the CPP call for concept notes in July 2001. In the concept note it is proposed that the work is led by the University of Zimbabwe with field activities undertaken in co-operation with the CARE Zimbabwe. CARE has proposed a project on "Protecting and promoting rural livelihoods in Masvingo Province" for DFID country funds. This will follow on from the project "Small dams and resource management" within which there was limited exposure of priming in demonstrations for communities with which CARE has been involved. The concept note to CPP proposes work on priming as one aspect of a group of technologies aimed at improving maize establishment and weed control. Project activities would rely on a participatory extension approach.

A journal paper combining the findings from studies with rice at IRRI and WARDA is planned. Publication of the findings from this strategic work on rice will inform future investigations.

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APPENDIX

PROJECT PUBLICATIONS