CROP PROTECTION PROGRAMME

Developing Weed Management Strategies for Rice-Based Cropping Systems in Bangladesh

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FINAL TECHNICAL REPORT

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FINAL TECHNICHNICAL REPORT

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EXECUTIVE SUMMARY

Project Purpose: This was "Improved and cost effective methods for the control of weeds in floodplain rice production systems developed and promoted." The project partnership, involving Bangladesh Rice Research Institute, International Rice Research Institute and Natural Resources Institute, UK, undertook work in farming communities in two areas of Bangladesh to develop and promote cost-effective rice weed management practices. Addressing this challenge had the potential to contribute to twin objectives of increased rice yield and improved labour productivity, central to the livelihoods of predominantly resource poor rice farmers who derive much of their income from rice sales. Work was undertaken in Comilla district, where up to two rainfed and one irrigated crop are grown each year, and in the Rajshahi district in the drier Barind Tract, where the predominant system is a single rainfed rice crop followed by fallow in the dry season.

Output 1 Crop and weed management practices and farmers perceptions of weeds and control measures described: A situation analysis using focus group discussion followed by questionnaire surveys confirmed that farmers perceive weeds to be a major constraint to system productivity. In the rainfed T- *aman* season labour availability, farm size, land tenure, and district (reflecting knowledge of new rice technology) were important determinants of the time of first weeding. Soil and climatic variables (toposequence, water depth) as well as socio-economic variables such as the availability of cash or labour were identified among a series of 21 different weed control decision criteria considered by farmers. In the irrigated *boro* season in Comilla timely weeding or application of herbicides must be co-ordinated with water supply but various problems cause shortages of irrigation water encouraging the growth of weeds and increasing labour costs for weeding. The project has described rapid adoption of herbicides over the past two years in Comilla by farmers seeking to reduce the use of hired labour to cut input costs, a trend that is predicted to continue. Farmers have little knowledge about herbicide action and use. This information needs to be provided through the supply chain and by extension. In Rajshahi district, the project has highlighted the problems of poor weed management (particularly late first weeding) and the potential adoption by households with various resources of innovations, including direct seeding and herbicides, to expand the scope for dryland *rabi* cropping by advancing the harvest of T.*aman*.

Output 2 Weed populations within different ecologies and the influence of crop and weed management practices described: On-farm yield gap studies in both Comilla and Rajshahi have highlighted that in the *aman* season some 30% of farmers loose at least 500 kg ha^{-1} rice at yield levels of 2.5 to 3.5 t ha^{-1} under current crop management practices. Significant losses of yield due to weeds with current farmer weeding practices were also recorded in the rainfed *aus* and irrigated *boro* seasons. The weed floras of both areas include a number of difficult to control perennial grasses (*Cynodon dactylon, Paspalum disticum*) which may become a problem under direct seeding.

Output 3 Persistence, dormancy and quantity of weed seeds in seed bank determined: Weed species composition and the soil weed seed-bank were monitored under different rice establishment, nutrient and weed management regimes over 3 seasons in a long term trial in Rajshahi. These data reflect long term potential changes in the weed flora that may result from changes in crop establishment method. Transplanting and flooding halved mean weed biomass in comparison to direct seeding. In direct seeding the herbicide oxadiazon was effective in reducing weed abundance of most species but not *Paspalum distichum, Cyperus iria* and *Eclipta prostrate. Alternaria sessilis* and *Cyanotis axillaris* were only recorded in direct seeded plots.

Output 4 Integrated weed management strategies to reduce the build-up of weed populations by regulation of soil seed banks which are appropriate to the farming system and cultural context of each area studied developed: On-station and on-farm trials were undertaken to compare a range of weed management practices for direct-seeded *aman* rice in Rajshahi and transplanted *aman* and *boro* rice in Comilla. Labour for in-crop weed control can be reduced by additional pre-plant tillage and herbicide use with direct seeding. Application of herbicides or use of a hand pushed weeder in transplanted rice result in similar yields to farmers' current practice of weeding twice by hand.

Output 5 Findings disseminated through IRRI Weed Ecology Working Group and at end of the project via a workshop for NGOs and extension staff: A range of dissemination activities have been completed in national, regional and international fora. These have included two end of project workshops for extension and NGO staff in Bangladesh, field days, participation in the regional Weed Ecology Working group and presentations in international conferences. Key results and recommendations have also been summarised in fact sheets for use by extension staff.

Contribution of Outputs to Project Goal: By building upon earlier work in Bangladesh and through a study of the effectiveness of weed management within existing systems, the project has contributed to an understanding of what the elements of cost-effective weed management strategies need to be, if these are to have an impact. As a result the knowledge gained by the project can be used as the basis for promoting improved weed management methods in the single rice *aman* crop and intensified multi-crop *aman-boro* and *aus-aman-boro* systems.

BACKGROUND

Importance of the researchable constraint

The 46.2. million hectares of rain-fed lowland rice in Asia supports many of the poorest people on the continent (IRRI, 1997). Various rainfall regimes, timing of floods and droughts, soil types, and topography all contribute to the environmental complexity of this environment. Because of the seasonal variability and spatial heterogeneity, the productivity of the rain-fed lowland systems remains low. Average rice yields are approximately 2.3 t/ha overall and are as low as 1.3 t/ha for the more flood-prone lands (IRRI 1997). Rice production is crucial to the economy of Bangladesh. Approximately 75% of the cropped area is devoted to rice production with some 60-70% of the agricultural labour employed in rice production, marketing and distribution (Ahmed, 2001). Widespread adoption of fertiliser-responsive modern varieties (MVs) and, the expansion of the area under irrigation have driven the increase in rice production over the past 40 years from 14.3 million tons in 1960 to 36.3 million tons in 2000. The expansion in irrigation facilities in the rain-fed lowlands has allowed intensification in cropping in many areas so that farmers are now able to grow an irrigated *boro* crop in the dry season as well as a rain-fed crop in the monsoon *aman*. However, to keep pace with internal demand it has been estimated that paddy production will need to increase from the current level of 22 million to 50 million tons by 2020 (Hossain, 2002). This represents an annual growth in yield of 1.5 to 2.0 % per year and will require per ha yields from the *aman* and *boro* crops to increase by 29% and 17 % respectively. It is important to focus on the double crop *aman-boro* system as nationally this pattern covers about 2 million ha, producing approximately 50% of the country's rice crop (Nur-E-Elahi *et al*., 1999). While plant breeding will continue to play a pivotal role, there has already been extensive adoption of high yielding MVs, which accounted for 56% of the total area planted to rice by 1998 (Mustafi *et al*. 2001). In Comilla District for example, which has long been in the forefront of adoption of modern rice production practices, 80% and 100% of *aman* and *boro* crops respectively were planted to MVs by 1999 (BBS, 1999). Future increases in rice production will therefore also depend on improvements in the efficiency with which inputs are used. Closing the gap between the rice yields achieved by the best farmers and those with only average yields has now become a high priority. Reducing this yield gap will largely depend on improvements in farmers' management practices. Rain-fed rice systems are dominated by the need for the timely establishment of the crop with the onset of rains, which typically shortens the time available for good land preparation and weed control. Weeds can be a particular problem in rain-fed low-land rice due to poor suppression by variable water levels (De Datta *et al.*1991; Hossain *et al.*, 1994) and the *T.Aman* (transplanted *aman*) crop in Bangladesh is no exception. The farmers' major weed management practices are hand weeding and the use of a push weeder. Effective weed control that will maximise yield involves farmers in a complex set of decisions that depend on a number of factors, particularly how well water can be managed and the availability and the cost of labour. Mamun (1998) observed 16% yield loss due to improper weeding of farmer-managed T.*Aman* rice in Bangladesh suggesting that farmers are either unable to begin weeding on time or with sufficient frequency.

Across 400,000 ha of the High Barind Tract of northwest Bangladesh climatic conditions are not suitable for double-cropped rice. Research conducted by a number of institutions including Bangladesh Rice Research Institute (BRRI), and Bangladesh Agricultural Research Institute (BARI) with support from ICRISAT and since 1999 the DFID Plant Sciences Programme (project R7540) has investigated opportunities for expanding the area planted to dryland crops in the *rabi* season. Work at Bangladesh Rice Research Institute (BRRI) has focused on a rice direct seeding system which could allow farmers to plant and harvest earlier and so be in a better position to use residual moisture for *rabi* cropping. Early planting may also reduce the risk of low rice yield due to terminal drought when the rains end before grain filling is complete. Increased weed competition in the young rice crop has however constrained the development and promotion of direct seeding. Improved weed management is therefore an essential component of attempts to increase productivity through direct seeding.

Demand for the project

Because the High Barind Tract represents 12% of the drought prone rain-fed lowland rice in Bangladesh it has been used as a "key" research site by the IRRI co-ordinated regional Rain-fed Lowland Rice Research Consortium (RLRRC) (Mazid *et al.,* 2001). Demand for research aimed at improving rice weed management in Bangladesh has been clearly identified by NARS members of the consortium. BRRI/RLRRC has implemented a programme of research in the Barind, close to the BRRI Rajshahi Regional Research Station, for nine years. Work by BRRI has led to the development and testing of a system which can allow farmers to increase cropping intensity by more reliable establishment of a *rabi* chickpea crop. This can be achieved by direct seeding a short duration rice cultivar to reduce field duration to 125-130 days, thereby releasing land when there is still sufficient moisture for *rabi* crop establishment. However, weeds are a major constraint to adoption as the advantage of effective weed control prior to transplanting through puddling is lost when rice is established by direct seeding. Farmers had found the weeding labour input to direct seeded rice unacceptably high in on-farm trials conducted by BRRI/RLRRC (Mazid *et al.,* 2001). Weeds constitute a major constraint to yield and the need to identify appropriate weed management practices within the context of improved crop establishment practices for dry seeded rice were identified as a priority area (Mazid *et al,* 1998).

Discussions at the CPP sponsored meeting on "Priority Setting for Rice Pest Management Research in Asia", held in Dhaka during April 1999, confirmed the need for increasing our understanding of the weed problems of the rain-fed lowlands. Stakeholder analysis undertaken for the DFID Dhaka based Poverty Eleviation Through Rice Research Assistance Project (PETRRA) reported that weed management, and the associated lack of weed control knowledge, are priority issues in *aman* and *boro rice* identified by farmers, extension officials and NGOs (Parul *et al*., 2000).

Previous research

Studies have been undertaken in various area of Bangladesh to characterise the diverse cropping patterns, soils and other agroecological characteristics of rice cropping (See comprehensive account by Brammer (2000). Recent research by BRRI has been summarised in a set of papers presented at a workshop in 1999 (BRRI, 1999). This has focused on germplasm improvement, cultivar performance under farmer management, soil nutrient/water management, pest management and mechanisation. In contrast little work has been done on weeds and weed management in Bangladesh. Information on the composition of the weed flora in various cropping patterns is only available at a national level (IRRI, 1989). There are also few studies on the impact of weed management practices, particularly at farmer level. Recent work by IRRI has largely been restricted to on-station studies, including herbicide testing for registration purposes. There is also limited information on the socio-economic context of weed management.

As described above BRRI/RLRRC collaboration has focused on improvement of rice production in the drought prone Barind tract. This programme concentrated on characterisation of the physical environment, cultivar and soil nutrient requirements, drought risk (Wade *et al*., 1999; Mazid *et al*., 1998; Saleh *et al*.. 2000). Work has also been undertaken to improve productivity through the introduction of dry seeding of the rice crop (DSR) (Mazid *et al.,* 2001). DSR offers a number of advantages. With only limited irrigation in the Barind, an opportunity for increasing cropping intensity lies with planting short duration crops e.g. mustard, linseed, or chickpea on residual moisture immediately after rice harvest. The reliability and productivity of a rice-chickpea system is improved when the rice is dry seeded (Mazid *et al*., 2001a). DSR yields are similar to those of TPR, but DSR matures 1-2 weeks earlier than TPR leaving a better soil-water regime for a subsequent non-rice crop (Saleh *et al*., 2000). The earlier maturity of DSR, can reduce the risk of terminal drought, allows timely planting and higher yields of chickpea with 16% and 30% reductions in labour and draught power requirements for rice crop establishment (Mazid *et al*., 2001a). The performance of a DSR-chickpea system has been confirmed in farmers' fields. However, weeds are a major constraint to adoption as the advantage of effective weed control prior to transplanting through puddling is lost when direct seeding (Mazid *et.al.*, 2001a). When the project was initiated in 1999 BRRI had begun to investigate options for improving weed control in direct seeded rice with one field trial in Rajshahi. There had however been little work to investigate direct seeding and weed control in the Barind within a livelihood or cropping system context.

PROJECT PURPOSE

The Project Purpose was: "Improved and cost effective methods for the control of weeds in floodplain rice production systems developed and promoted."

The project was therefore designed to develop and promote improved and cost-effective methods for the control of weeds in floodplain rice production systems. Addressing this challenge had the potential to contribute to twin objectives of increased rice yield and improved labour productivity, central to the livelihoods of predominantly resource poor rice farmers who derive much of their income from rice sales. Studies were designed to focus on:

- Characterisation of rice cropping systems, focusing on the role of weeds as a constraint to yield and system productivity. The objective was to understand both agronomic and socio-economic dimensions of weeds as a yield constraint, and their interactions to provide a systems framework for the development of weed management practices.
- Understanding of the impact of weeds and factors that determine variability in weed flora composition and persistence, to provide a basis for the integration of crop establishment and in-crop weed control practices which impact on the long term persistence of weeds.
- Evaluation of the role of weed management practices in reducing yield loss due to weeds and improving labour and system productivity.

RESEARCH ACTIVITIES

Research partnerships

The project brought together agronomists, weed scientists and agricultural economists/socio-economists of Bangladesh Rice Research Institute, International Rice Research Institute (IRRI) and Natural Resources Institute (NRI). For implementation of on-farm trials and to field day and dissemination workshop activities BRRI staff maintained liaison with the Department of Agricultural Extension. During the course of the project the following staff made inputs to this research:

Bangladesh Rice Research Institute

Dr J U Ahmed, Head Agronomy Division and co-ordinator of activities at Comilla and Gazipur
Dr M A Jabber, Agricultural Economist
Dr M A Mazid, Head Rajshahi Regional Station and co-ordinator of activities in the Barind
Dr Lotif, S. Hassan, M A Badshah, M K A Bhuiyan, and Biswajit Karmakar

International Rice Research Institute

Dr A M Mortimer, Weed Ecologist
Dr L Wade, Crop Physiologist
R T Lubigan and J D Janiya, NRS Weed Scientists

Natural Resources Institute

Dr C R Riches, Weed Scientist and project leader
Dr A Orr, Agricultural Economist
Dr EJZ Robinson, Agricultural Economist

Research sites

Work was undertaken in two areas of Bangladesh representative of three levels of cropping intensity. Rajshai and Comilla Districts were chosen as potential developments in the rice cropping systems in these areas have important implications for the future composition and abundance of weed populations.

The High Barind Tract in Rajshahi District: The Barind Tract is a distinctive physiographic unit that occupies one-quarter of Rajshahi Division in north-west Bangladesh. The High Barind comprises 400,000 acres of dissected terraced fields with a height of 5 m between high and low fields. Rainfall during June to October is sufficient for one rice crop. This is vulnerable to late-season drought during grain filling in October. Soils are Grey Terrace Soils with low moisture-holding capacity and organic matter content. *rabi* cropping is limited by soil moisture and a strong plough pan that restricts root penetration, reducing the amount of moisture crops can actually use. Due to the limited irrigation potential of the area there is relatively little production of *boro* (irrigated) rice in the dry *rabi* season. Small areas of wheat, requiring one irrigation, are produced adjacent to farm ponds. Chickpea, linseed or mustard may be planted season but farmer preference for the late maturing, but high quality, rice cultivar Swarna (135-145 days duration) reduces that opportunity for establishing these crops on residual moisture. Thus much of the land lies fallow during the *rabi* season. Cultivation intensity is approx.120%. Absentee landlords hold much of the land and there is a predominance of sharecropping (Maniruzzaman *et al*., 1991). Members of the *adivashi* (tribal) community commonly work as field labourers. The Barind represents 12% of the drought prone rain-fed lowland rice in Bangladesh and has been used as a "key" research site by the IRRI co-ordinated regional Rain-fed Lowland Rice Research Consortium. Recent research by the consortium in the area has concerned characterisation of the physical environment, cultivar and soil nutrient requirements, drought risk (Wade *et al*., 1999; Mazid *et al*., 1998; Saleh *et al*.. 2000) and improving productivity through the introduction of dry seeding of the rice crop (DSR). BRRI has implemented this programme of research on land rented from farmers at the key site village of Rajabari, close to the BRRI Rajshahi Regional Research Station, for the past 9 years. The project work programme for the area was agreed with BRRI and IRRI members of RLRRC and incorporated into activities of the consortium. Researcher managed trials were undertaken at the Rajabari key site and on-farm studies were implemented in three villages where consortium activities had previously been carried out.

Intensive systems in Comilla District: With some 50% of the 482,000 ha of cultivated land in Comilla District under irrigation double rice cropping (57% of the area) and triple rice cropping (26%) result in a cropping intensity of 188% compared to a national average of 134%. Rice can be produced in three seasons. The *boro* – irrigated in the dry *rabi* season; *aus* - rain-fed in the pre-monsoon period; and *aman* – the most widely used season in which rice is transplanted at the onset of the monsoon. T.*aman* is found in two cropping patterns of which the double crop *boro* – Fallow – T.*aman* pattern occupies the largest area in the district with an average rice productivity of about 8 tons/ha (Nur-E-Elahi et al., 1999). The triple crop *boro*-T.*aus*-T.*aman* system can produce up to 10 tons ha^{-1} and is also a major cropping pattern in district (Nur-E-Elahi *et al*., 1999). Comilla district was in the forefront of the adoption of Green Revolution technology. For example all *boro* is planted to modern high yielding cultivars as is 80% of the T.*aman* and 55% of the *aus* crop (BBS, 1999). Characterisation studies and on-farm trials were undertaken in two villages, one with a *boro*-T. *aman* system and the other with a *boro*-*aus*-T.*aman* system. A project site office was established in each village to provide a focal point for meetings of participating farmers. In one village the DAE Block Supervisor co-ordinated the farmer group while at the other location an assistant employed by the project. Supporting research trials were undertaken at the BRRI Comilla Regional Station.

Trials at Gazipur: Evaluation of the weed competitiveness of some rice lines was undertaken on the farm at BRRI HQ at Gazipur.

Characterisation studies:

Field research was conducted using a methodological mix structured questionnaire surveys, focus group discussions, and household case-studies. These have proved mutually reinforcing and given extra depth to the analysis of farmers' weed management.

<u>Situation analysis</u>: RRAs were conducted in October 2000 at project sites in both Comilla and Rajshahi districts in October 2000. Multi-disciplinary teams comprising researchers and DAE staff undertook these. This initial study (Jabber *et al*., 2002) provided a situation analysis of rice farming with a focus on weed management. Information provided by focus groups was used to draw up a programme for social science research. Issues identified for in depth analysis included:

- farmers' weed management practices, the effects of land tenure on weed management, the use of weeds as livestock feed and the potential profitability of new approaches;
- the importance of water control for weed management in *boro* rice;
- the scope for dryland (*rabi*) cropping in the off-season in Rajshahi;
- information flow on herbicides;

- the impact of herbicide adoption on rural employment;

Farmers' weed management for T. *aman*: A questionnaire survey was made of farmers weed management practices for a stratified random sample of 209 farmers from study villages both in Comilla and Rajshahi districts. The survey objectives were to (a) capture variation in weed management practices (b) determine the scope for improvement in farmers' practices**.** The survey was conducted in January 2001 after the harvest of the *aman* crop in November 2000.

Farmers' decision-making for weeding T. *aman*: Household case-studies were made with 13 farmers in the two project villages in Comilla district to explore farmers' decision-making for first weeding of rain-fed T. *aman*. The objective was to identify factors that might delay weeding and increase crop losses to weeds during the critical first 30 days after transplanting.

Water management for weed control in irrigated *boro*: A stratified random sample of 90 farmers from two project villages and one non-project village in Comilla district was surveyed in the 2000/01 *boro* season. The aim was to analyse farmers' weed management practices for irrigated rice, and the socio-economic constraints on efficient weed management. In addition, case studies were made of two Shallow Tube Well (STW) command areas (one in each project village) during *boro* 2002 to investigate interactions between water management and weeding. Detailed plot-level information was collected on water status in relation to time of first and second weeding, and number of dry days between weedings, for each plot within the STW command area. Information was also collected on farmers' views of the efficiency of water management, and labour use for weeding.

Constraints to the expansion of *rabi* cropping: A stratified random sample of 91 farm households from 12 villages in three *thanas* in Rajshahi district was surveyed to explore socio-economic issues relevant for improving weed management and cropping intensity in the High Barind Tract. The survey was conducted in March 2002 after the harvest of the *aman* crop planted in 2001 and the planting of rabi crops to be harvested in 2002. Of the 119 farmers from Rajshahi district surveyed in 2000, the majority was surveyed for the *rabi* crop in 2001. Hence, both the *aman* 2000 and *rabi* 2002 surveys essentially cover the same set of households.

Herbicide adoption in Comilla district: A study was undertaken at the beginning of the 2002 *boro* season of information flow down the herbicide supply chain in Comilla and of perceptions of herbicides among early adopters. Information was collected through interviews with pesticide dealers in village bazaars and with 12 farmers who had used a herbicide.

Herbicides and the labour market**:** Household case studies were made with 13 farmers in Comilla district to explore recent changes in the labour market for weeding.

Understanding the impact of weeds

Rice yield loss estimates: Yield gaps due to weeds, under existing farmer weed management practices, have been estimated for two years in T. *aman* in Rajshahi and for T. *aman, boro* and T.*aus* in Comilla. During the first year yields were recorded from portions of farmers' rice fields left unweeded, maintained weed free (by weeding at 21, 35 and 48 days after transplanting in addition to weeding completed by the farmer) or weeded by usual farmer practice. The farmers undertook cultivar choice and all other crop management according to their usual practices. A nutrient component was added to the study in the second season in order to partition yield loss due to weeds and soil nutrient status. This was achieved by including plots to which a recommended dose of basal N:P:K and top-dressed N was added. Fertiliser doses were based on BRRI rice management recommendations. In three villages in Rajshahi, sites were studied at three terrace positions on the toposequence. In each village six sites were selected at each of "high", "medium" and "low" toposequence position as defined by farmers. This resulted in a total of 54 sites in the area in year one. In the following season 18 sites were used in total. In Comilla 20 sites were studied in each of two villages in year one during T. *aman* and *boro* and 10 per village during *aus*. This was reduced to 5 per village in the second season.

Weed species inventories and identification of problem species: Weeds present at each of the yield loss sites were listed at maximum tillering and the five most abundant species were noted.

Effects of rice establishment and weed control method on weed abundance and species composition: Direct seeding has yet to be adopted in *aman* rice in Rajshahi. It was therefore decided to use a long term experiment (LTE), including combinations of crop establishment and weed control practices for a rice/chickpea rotation, to examine possible effects on the weed flora. The LTE, which is on going at Rajabari, was established by RLRRC on a medium toposequence position during *aman* 1999. With the inception of this project, modifications were made to the trial for 2000 and the current treatment combinations have now run for three seasons. In 2000 data on weeds was collected by "weed group" (broadleaf, grasses and sedges). Detailed monitoring of weed number and biomass by species was undertaken in 2001 and 2002. A quantitative estimate of the weed seedbank, as effected by cropping practice, was made by evaluating soil samples in seed pans. This involved counting weed seedlings emerging from samples of soil taken from plots following chickpea harvest in 2001 and 2002. Each sample was divided in two, with half maintained under aerobic and the other half under saturated conditions.

Evaluating the role of weed management practices to reduce yield loss and improve productivity

Rajshahi

Fully replicated trials in the *aman* season at the Rajabari key site:

Long term experiment: Undertaken on the medium toposequence position - comparing rice yield and weed population response to different rice crop establishment, nutrient management and weeding practices. The aim of the trial is to optimise the productivity of system in which *aman* rice is immediately followed by *rabi* chickpea. A full description of the treatments is given under output 4.

Evaluation of weed control practices on high and medium toposequence: Assessment of weed management for direct seeded rice had been initiated during 1999 *aman* by BRRI/RLRRC. Data from this season was initially analysed by the current project before a modified trial was conducted in 2000 and 2001. Timing of pre-plant tillage and in-crop weed control by herbicides, mechanical and hand weeding were compared.

Evaluation of pre-plant priming for rice and chcikpea: Overnight soaking of rice and chickpea seed has been demonstrated as a method for improving crop establishment by the DFID Plant Science Research Programme including work in Rajshahi district by project R7540 (Harris *et al.*, 1999). A proposed additional benefit of priming is an earlier harvest. If the rice harvest could be advanced, by even a few days, by priming this may increase the window of opportunity when soil is moist enough for planting a *rabi* crop following a direct seeded, short duration rice cultivar. Priming was therefore evaluated in two seedbed conditions for two seasons as a possible component of the direct seeding system.

Comilla

On-farm evaluation of weed management practices in *aman* and *boro* sesons: Trials were conducted at five sites in each of two villages in Comilla in *aman* 2001 and *boro* 2002 to evaluate weed control and rice crop performance following use of a herbicide, use of a push weeder designed by BRRI or farmer practice in transplanted rice. Two herbicides which are being promoted in Comilla were used – Rifit (pretilachlor) in Chowara and Set Off (cinosulfuron) in Paruara. Tillage, crop establishment, water and nutrient management were undertaken by the farmers hosting the trials. Project staff provided assistance to farmers with herbicide application.

Weed competitiveness in rice

Studies funded by DFID IPM Strategy Area and CRF funds at West Africa Rice Development Association (WARDA) in W. Africa and recent work at IRRI have demonstrated that large differences exit in the competitiveness of rice cultivars with weeds. This project has supported field-work at BRRI HQ, Gazipur, to characterise the morphological traits that are thought to be associated with competitiveness of local and introduced lines. Morphology was initially assessed in non-replicated plots used for seed multiplication. When sufficient seed was available replicated trials were undertaken with the rice lines grown under weed free and unweeded conditions. WARDA provided 22 lines for this study including 11 *Oryza glaberrima* x *O. sativa* inter-specific hybrids.

Dissemination activities

These were undertaken a various stages of the project and in various fora. At international level two papers were presented at the Brighton Crop Protection Conference in 2001. In the region BRRI staff collaborating with the project attended meetings of the Weed Ecology Working Group (WEWG). This is a small thematic group of collaborating NARES with the common strategic goal of developing integrated weed management practices for rice in south and south-east Asia. This project has supported the attendance of Dr J. Uddin at two work group meetings (IPM-net, Chang Mai, March 2000; IRRC, Bangkok 2002) and Dr M Mazid (Bangkok, 1999). Dr Mazid also presented project findings to meetings of the RLRRC in India in 2001. The format of the consortium was subsequently changed to Consortium for Unfavorable Rice Environments (CURE) on which Dr Mazid continued as key site representative for Rajshahi. Within Bangladesh dissemination of findings took place at a field day for extension workers and farmers held at Rajabari in March 2002, and farmer field days held in Comilla during *boro* 2002. Three workshops were organized. An annual review and planning workshop took place at BRRI Gazipur in March 2001 in collaboration with RLRRC. End of project workshops were held in Comilla and Rajshahi in September 2003 to present project finding to staff do the Department of Agricultural Extension and NGOs.

Key results were summarised in Bengali in leaflets distributed to extension and NGO staff at the end of project workshops.

OUTPUTS

Output 1: Crop and weed management practices and farmers perceptions of weeds and control measures described

Farmers' weed management practices**:** The findings of studies undertaken by the project to characterise weed management problems in Comilla and Rajshahi, to understand existing methods of weed control, farmers perceptions of these and the role possible modifications to current practices have been reported in two project working papers (Jabber *et al.*, 2002; Orr and Jabber, 2002a). Weed management practices in T. *aman* varied widely between districts, within districts, and between farms. Significant differences were found in the number of tillage operations, type of tillage, frequency of weeding, and particularly the date of first weeding. Mean date of first weeding ranged from 15 days after transplanting (DAT) in Comilla to 28 DAT in Rajshahi, from 11-19 DAT between farms in Comilla, and between 13-33 DAT for the sample farms as a whole. Variation in the timing of second weeding was less significant. These variations suggest considerable scope for improving farmers' weed management practices and reducing yield losses from weeds in T. a*man*.

Regression analysis showed that labour, farm size, land tenure, and district (reflecting knowledge of new rice technology) were important determinants of the time of first weeding. Weed growth (determined by landtype, water levels in the plot, and the use of mechanised tillage) was not a significant determinant of the timing of first weeding once other factors were accounted for.

On average, the combined effect of labour, tenure, area planted, and district delayed first weeding by 18 days. The breakdown was as follows: area planted, 1.2 days; rented plot, 2.5 days; using hired labour, 1.4 days, non-availability of labour, 1.9 days; and the dummy for Rajshahi district, 10.6 days. These results suggest that improving farmers' weed management to reduce yield losses from weeds can be achieved by (a) training farmers in optimum time of weeding and (b) greater use of labour-saving technology such as herbicides and rotary weeders.

Sharecropping adversely affected weed management. Sharecropped plots were less likely to be given mechanised tillage and were weeded less frequently and later than owned plots. They were also less likely to grow modern varieties (MVs). Farmers may have preferred to grow the local *aman* variety Swarna on their sharecropped plots because its longer field duration ensured higher yields and hence increased the net amount of paddy retained by tenants. If so, then farmers might be less willing on sharecropped plots to adopt innovations (direct-seeding, early-maturing MVs) that increased scope for *rabi* cropping but reduced *aman* yields. Conversely, they might be more willing on sharecropped plots to adopt innovations like herbicides that boosted *aman* yields by reducing crop losses from weeds.

Farmers' decision-making for weeding T. *aman*: The information from household case-studies undertaken to explore farmers' decision-making in Comilla was structured in the form of a hierarchical decision-tree (Jabber et al, 2002). The objective was to identify factors that might delay weeding and increase crop losses to weeds during the critical first 30 days after transplanting. This research identified a series of 21 different decision criteria. These included physical and climatic variables (toposequence, water depth) as well as socio-economic variables such as the availability of cash or labour.

Late first weeding on medium and high land was primarily the result of edaphic and climatic factors outside farmers' control. Farmers were prevented from weeding by delayed rainfall that made the soil too hard to weed. Unless they chose to irrigate, they had to wait for rain to soften the soil. Small farmers may be more likely to irrigate under these circumstances because household food security based on own production is more critical for such farmers. First weeding may also be delayed by excessive rainfall that makes the soil too soft for use of the rotary weeder. This forces farmers to weed by hand, which is slower and usually requires hired labour. On low-lying land or on land where water-depth exceeds 3 inches, farmers could not use the rice weeder and relied entirely on hand weeding. Farmers did not normally use the rice weeder for second weeding for fear of damaging the roots of the rice plant.

Water management for weed control in irrigated *boro* rice: Continued growth in rice production in Bangladesh is heavily dependent on higher yields from irrigated *boro* rice, the main source of productivity growth during the Green Revolution. Increasing *boro* yields will require reducing crop losses from weeds, which in turn will require better water management to minimise weed growth. An analysis of the interactions between weed and water management for *boro* rice has been summarised in a working paper (Jabber and Orr, 2002c) based on a study undertaken by the project in two shallow tubewell command areas in Comilla. A number of problems were highlighted in particular, power cuts, mechanical breakdowns, and greater competition for water with interruptions in supply. This has serious implications for efficient weed management, since timely weeding/application of herbicides must be co-ordinated with water supply.

A shortage of irrigation water encourages the growth of weeds and may increase labour requirements for weeding. On plots where dry days increased weeds, an average of 14 dry days accounted for one-third of the period between transplanting and second weeding. The cost of poor water management includes not only higher yield losses from weeds but also higher labour costs for weeding. The average increase in labour requirements was 6.2 mandays/acre or 15.3 days/ha. The average increase in labour costs (valuing all labour at the average wage rate for first and second weeding) was 701 Tk/acre (1731 Tk/ha). By comparison, farmers reported that irrigation for *boro* cost roughly 1750 Tk/acre (4323 Tk/ha) (Jabber et al, 2002). In terms of additional weeding, therefore, the cost of poor water management was roughly one-third the cost of irrigation. Farmers with poorly irrigated plots effectively paid one-third more for irrigation.

The timing of weeding for Boro was significantly related to water management. The main variables that delayed weeding on a given plot were (1) the absolute number of dry days and (2) the length of time that elapsed between irrigations. Obviously, these two variables are related, since dry days are likely to be more frequent where there are long periods between irrigations. These results suggest that farmers delayed weeding on plots where they were unsure about the timing of irrigation. On the other hand, on plots where the frequency of dry days amounted to a high share of time between transplanting and first weeding, or between first and second weeding, then farmers weeded earlier, presumably because they feared high crop losses from weeds on these plots.

Herbicide adoption; an increasing trend: In October 2000 none of the farmers in Comilla district, who participated in project focus group discussions about weed management, had ever used a herbicide in rice (Jabber *et al*. 2002). Farmers indicated that they did not use herbicides because of lack of knowledge on their use and non-availability. By the *boro* season of 2001 herbicides became more widely available with agrochemical companies and their dealers promoting their products through on-farm demonstrations in a number of areas of Bangladesh including Comilla. Farmer interest in adoption of herbicides was found to be increasing rapidly, when Chowara and Paruara were visited again in September 2001, largely because use of chemical weed control results in significant reductions in production costs as indicated above.

As farmers begin to adopt herbicides it is important to ensure that appropriate, accurate information is available so that they can be used effectively and safely. This is particularly so in areas like Comilla where there is a significant knowledge gap about their action and use. A project working paper (Riches *et al*., 2002) has reported on the initial adoption of herbicdes in Comilla and focused on the key question: Do pesticide dealers and farmers have access to sufficient information about rice herbicides? The main findings were:

- A number of herbicides have become widely available in Bangladesh since they were launched in 2000 to 2001 and following the promotion campaigns undertaken by the producing companies, which include farmer group meetings and field demonstrations, a steady increase in farmer adoption has been occurring.
- Most of the farmers who are now using herbicide began to adopt chemical weed control either in 2001 or during the 2002 *boro* season. In most communities there had been no previous herbicide use. Those who have adopted herbicides to date tend to be farmers with the larger land holdings and with other income in addition to farming.
- The agrochemical company promotion programmes have raised awareness of chemical weed control in the farming community and farmers have relied upon company representatives and pesticide dealers in the bazaars for information on the dose, timing and application method.
- Liquid or wettable granule formulations are being applied either by use of a locally fabricated sprayer, on a spray volume to area basis utilising a cone nozzle, or by hand broadcasting of the herbicide mixed into urea fertiliser. Farmers are applying a granular herbicide by broadcasting in a mixture with fertiliser or sand. Although application rates tend to be less than the label recommended dose, farmers are achieving good weed control. The motivation for adopting herbicides is to save input costs in a tightening labour market. Farmers commonly hire labour to weed by hand or with a mechanical push weeder, but by using chemical weed control it is possible to save Taka 990 to 1320 per ha at current labour costs. Pesticide dealers and farmers expect that adoption by other farmers will be rapid.
- Pesticide dealers and company representatives have played a key role in providing farmers with information about herbicides where before there was a knowledge gap on chemical weed control in the farming community. Government agricultural extension staff in some villages have been working with the companies, but have not been provided with any training on herbicide use.

<u>Will herbicides disadvantage the rural poor?</u>: Project R7471 identified two aspects of the adoption of improved weed management which are sometimes argued to disadvantage some of the rural poor. Farmers' weed management practices affect not only rice yields but also employment opportunities for landless labour and fodder supply for livestock. Weed management innovations therefore require a systems perspective that takes account of linkages between weeding and other components of the farm economy.

Herbicide adoption reduces employment for weeding. Since most labour for weeding is supplied by landless people or households with small land holdings, including migrant labour from regions with less favourable rice environments, herbicides may be viewed as harming the livelihoods of the poor. The project has considered if this is a valid assumption. Household case-studies in Comilla district explored recent changes in the labour market for weeding (Jabber et. al., 2002). Results showed that the impact off herbicide adoption is complex, and will not necessarily disadvantage poorer households in Bangladesh.

Farmer interviews suggested a tightening labour market in Comilla. Demand for weeding labour has increased following adoption of short-strawed MVs that are less efficient at shading out weeds, and because tractors and power tillers (hired for limited periods) are less effective in killing weeds. Farmers reported that before the advent of mechanised tillage they rarely weeded twice. Farmers have tried to reduce labour costs by using the rotary weeder but this is unsuitable for low land or for second weeding when it may damage the rice roots.

Farmers reported that several changes in the labour market. Hiring was no longer restricted to market days, contracts were no longer fixed in advance, and labourers no longer worked for the same employer for long periods. Working hours had been reduced from 7 am-6 pm from 7 am – 4 pm. The market was also reported as more fluid with greater variation in wage-rates. Cash wage rates for first weeding (last week August-first week September) had risen from Tk 30-35 five years ago to Tk60-80 in 2001, whereas the price of rice in the same period had risen by only 2 Tk/kg. This suggests growing competition in the labour market for weeding.

These changes in the labour market are to be expected given relative shifts in supply and demand. On the supply side, the recent Agricultural Census showed no change in the number of agricultural labour households between 1983-96 (Hossain, 2000). On the demand side, the rapid spread of irrigation and adoption of MV *boro* rice in the 1990s has increased demand for farm labour. At the same time, non-farm employment has expanded rapidly. Most of the increase in rural employment since the 1980s has occurred in the non-farm sector. Wage-rates in the non-farm sector are about a third higher than in agriculture, encouraging movement from the agricultural sector and contributing to seasonal labour shortages. At the same time, rapid technology change in rice production has kept rice supply ahead of demand and real rice prices have fallen. The cumulative effect of these changes has been to raise real wage-rates in agriculture.

Herbicide adoption, therefore, will not is not necessarily disadvantage poor households because:

1. Demand for agricultural labour will continue to grow as farmers continue to adopt MVs and diversify out of rice into higher-value crops. There is still significant scope for expanding the area under irrigation and increasing coverage of MVs in the *aman* season. Since these are more labour-intensive than LVs, this will increase aggregate demand for agricultural labour.

2. Non-farm employment is expanding rapidly, and rural-urban migration. This is not a closed economy where herbicides will result in a zero-sum redistribution of income from landless labourers to farmers (including resource-poor farmers), but an open economy in which loss of employment in agriculture may be offset by employment opportunities in other sectors.

3. Higher rice production will lower rice prices. By cutting unit costs, herbicides will encourage MV production and thereby increase rice supply. Since domestic prices are still some 5-10% above world levels, this will lead to further falls in the price of rice. This fall will largely benefit poorer consumers who spend two-thirds of their income on food, 40 % on rice alone (Hossain and Shahabuddin, 1999). By reducing crop losses from weeds, herbicide will also increase net yields, further stimulating production and lowering prices.

4. The bottom line is that average rice yields must grow by 3 % per annum over the next 15 years to ensure that Bangladesh remains self sufficient in rice (Hossain, 2000). Most of this increase must come from the irrigated rice ecosystem. Meeting this target will require reductions in unit costs to provide economic incentives for rice producers. Herbicides can play an important role in providing this price incentive, maintaining rice supply, and contributing to further declines in poverty by ensuring low rice prices.

To what extent will herbicide adoption adversely affect fodder supply? Straw is a major source of fodder but in Comilla district two-thirds of sample households also fed livestock with weeds from their own fields and one-third fed livestock weeds from others' fields. Very few farmers reported that hired labourers removed weeds for use as livestock feed. Loss of fodder represents a hidden cost of herbicide adoption, and farmers in Comilla district who are already adopting herbicides may need to compensate by introducing new, fast-growing plant species to maintain an adequate fodder supply for livestock. Straw is already a major source of fodder and straw sales provide income to large and small farmers alike. Increased straw availability will be achieved alongside increased rice yield associated with improved weed control. This will partly offset reductions in the quantities of weeds available for fodder.

Weed management and the expansion of *rabi* cropping in the Barind: A study of socio-economic issues relevant for improving weed management and cropping intensity in the High Barind Tract have been reported in a project working paper (Orr and Jabber, 2002b). Survey findings have important implications for the design of interventions, their relevance for specific groups of farmers, and understanding their potential to raise productivity and reduce poverty in a region of Bangladesh that has been largely bypassed by the Green Revolution.

Late weeding is a feature of the T. *aman* rice crop in Rajshahi district. The study provided more evidence of a labour constraint for weeding, particularly on large farms. Despite high participation rates for weeding among adult male family members, most households relied primarily on hired labour for weeding. Hired labour was local rather than migrant, which may intensify competition for labour. The absence of migrant labour may reflect low wage rates in the High Barind caused by a higher proportion of landless and marginal farm households that supply agricultural labour as well as the supply of cheaper female labour from tribal (*Adivasi*) households. Herbicides that reduce labour costs seem likely to be widely adopted, displacing local labour. The impact of this change on the livelihoods of landless households needs further research.

Direct-seeding of *aman* and early-maturing modern rice varieties (MVs) (eg. BR32) are expected to result in earlier harvesting, allowing farmers to expand the area planted to *rab*i crops using residual soil moisture. However, caution is needed in extrapolating results from On-Farm Trials (OFTs) to farmers' fields. Survey results show that farmers harvested MV T. aman at the same time as Swarna, the dominant local variety (LV) with a longer field duration. This may be due to harvesting contracts that make it more convenient for farmers to harvest MVs and LVs simultaneously. Thus, the timing of harvest is dictated by the dominant variety of T. *aman.* If this analysis is correct, then DSR and early-maturing MVs will not necessarily be harvested earlier than other *aman* varieties. Earlier harvesting will only occur when Swarna finally ceases to be the dominant *aman* variety. Bringing forward the timing of the *aman* harvest, therefore, will require the widespread adoption of a short-duration MV that outyields Swarna.

Decisions about *rabi* cropping differed significantly between large and small farms. Generally, on small farms *rabi* crops were more likely to be planted on unfavourable soils, following the long-duration variety Swarna, and on sharecropped plots that might have been less fertile than others. Similarly, on small farms the decision to plant Swarna was not influenced by soil type or the need to plant a *rabi* crop but primarily by consumption pressure or the need to maximise *aman* yields from limited land. Thus, small farms have fewer choices about whether or on which plots they may plant *rabi* crops, and less choice about where to grow Swarna or MVs. As a result of consumption pressure on limited land, cropping intensity in the *rabi* season was significantly higher on small farms.

Interventions to expand *rabi* cropping in the High Barind may distinguish two broad target groups:

- Larger farms with lower cropping intensity and the potential to grow *rabi* crops under relatively favourable conditions. Interventions for this group should focus on raising the area planted.

- Smaller farms with higher cropping intensity and limited potential to grow *rabi* crops under favourable conditions. Interventions for this group should focus on raising yields.

<u>Conclusions and Implications:</u> The Bangladesh economy is now launched on a growth path that will make it a middle-income economy by 2020. This structural change will have a profound impact on the rice sector of the rural economy. Among these impacts are the continued decline in the real price of rice and the growing competition for labour with the non-farm sector, which is now the fastest-growing source of employment in the rural economy.

This macro-economic perspective is essential for understanding the need for improved weed management, and the forms that such improvement might take. Farmers confronted with a cost-price squeeze in rice production will either diversify out of rice or seek new ways to cut unit costs. In districts of intensive rice cultivation like Comilla, where rice is double or triple-cropped, the scope for savings in unit costs is limited since tillage and post-harvest operations are already mechanised. Weeding, however, remains highly labour-intensive and competition for labour has intensified. This explains the widespread interest in herbicides. Aided by aggressive marketing from chemical companies, conditions are now ripe for a massive expansion in herbicide use. This will reduce employment for agricultural labour but (as argued above) the indirect benefits will be transmitted largely to the poor through continued low rice prices. Also, it must be remembered that the direct beneficiaries will include resource-poor farmers and sharecroppers who also employ hired labour for weeding.

The consequences of rapid herbicide adoption require further study. Herbicide adoption is just beginning in Bangladesh, so research would be timely. The results are likely to take forward donors' thinking about labour-saving technology, which is conventionally regarded as harming the poor.

So far farmers have been able to obtain sufficient basic information to enable them to use herbicides effectively. As the number of farmers adopting herbicides increases, as products become more widely available, there is a need for the extension service, companies and other stakeholders to get together to plan for a more comprehensive provision of information on a number of non-product specific issues. These include application, safety, water management after application, fate of herbicides in the soil and preventing the development of herbicide resistant weed populations.

In Rajshahi district, socio-economic research has highlighted the problems of poor weed management (particularly late first weeding) and the potentially adverse effects of sharecropping on the adoption of innovations to expand the scope for dryland rabi cropping by advancing the harvest of T.*aman*. Late first weeding primarily reflects a knowledge gap. Unlike farmers in Comilla district, farmers in the Barind Tract have had relatively little exposure to new rice technology and may have been poorly served by research and extension. Training farmers in Rajshahi district in improved weed management would give high returns.

The problem of sharecropping is more contentious, but the evidence from Rajshahi suggests that sharecroppers would not be averse to innovations that improved yields of T. *aman*. Herbicides fall into this category. They might, however, be less willing to adopt innovations that offered greater scope for *rabi* cropping but that also reduced *aman* yields. Direct-seeded rice and early-maturing MVs fall into this category. The economic calculus here is complex, however, and cannot be determined *a priori*. Farmers in Rajshahi have chosen to cultivate a local *aman* variety, Swarna, that gives a higher yield than currently available MVs but whose long field duration limits the scope for subsequent dryland rabi crops. We assume that farmers had good reasons for making this decision. Changing this calculus will require the introduction of a commercially-attractive *rabi* crop that gives farmers an economic incentive to switch away from Swarna. Chickpea may fit the bill, but farmers must first be convinced of its market potential before they will sacrifice *aman* yields.

Finally, closing the yield gap in irrigated rice production will require a research focus on the interface between water, weed, and fertiliser management. An integrated crop management (ICM) is essential if farmers are to close the yield gap in irrigated rice production, on which rice supply in Bangladesh now largely depends and where research can have a major impact. Future work on weed management on irrigated rice must therefore broaden its scope to address wider issues of crop management.

Output 2: Weed populations within different ecologies and the influence of crop and weed management practices described.

What are the yield gaps due to weeds? The yields of rice achieved by farmers are often below attainable levels due to a number of factors including sub-optimal use of inputs and poor management. A major component of the field programme of the project therefore concentrated on determining the component of the yield gap which can be ascribed to sub-optimal weed management. Yield gaps due to weeds, under existing farmer weed management practices, have been estimated for two years in T. *aman* in Rajshahi and for T. *aman, boro* and T.*aus* seasons in Comilla. During the first year yields were recorded from portions of farmers' rice fields left unweeded, maintained weed free (by weeding at 21, 35 and 48 days after transplanting in addition to weeding completed by the farmer) or weeded by usual farmer practice. Cultivar choice and all other crop management was undertaken by the farmers according to their usual practices. Only unweeded and weed free plots were marked out at each site. An estimate of yield under farmer management was taken from an unmarked portion of the field to avoid any bias. A nutrient component was added to the study in the second season in order to partition yield loss due to weeds and soil nutrient status. This was achieved by including plots to which a recommended dose of basal N:P:K and topdressed N was added. Fertiliser doses were based on BRRI rice management recommendations. Results for 2000 T.*aman* have been presented in Ahmed *et al*; (2001) and Mazid *et al.,* (2001).

TABLE 1. Components of yield gaps due to weeds on plots with no weeding, farmer weed management or when farmer managed plots are kept weed free for 50 DAT. Mean yields (t ha^{-1}) on 18 fields of three villages – range of yield gap components shown in brackets – Rajshahi T.*aman* 2000. (Mazid *et al.,* 2001)

Village	Weed free yield	Potential yield gap with no weeding	Yield gain with farmer weeding practices	Additional yield gain with intensive weeding
Tanore	3.82	0.79	0.43	0.36
	(2.45 – 4.72)	(0.43 – 1.20)	(0.41 – 0.76)	(0.11 – 0.53)
Nachole	3.99	0.94	0.47	0.47
	(3.43 – 4.72)	(0.08 – 1.23)	(0.29 – 0.67)	(-0.48 – 0.861)
Rajabari	3.59	0.61	0.33	0.29
	(2.21 – 4.42)	(0.10 – 1.68)	(-0.01 – 1.01)	(0 – 1.31)
S.E.M.	0.087	0.046	0.029	0.035

A summary of the effects of weed and nutrient management on grain yield for *aman* 2000 and 2001 across 54 and 18 farmers fields respectively in three villages in Rajshahi District is presented in Figure 1. Six fields in 2000 and two fields in 2001were on each of three toposequence positions, identified by farmers as "upper", "medium" and "low ", covering little more than 5 m difference in elevation overall. When weed competition was completely removed by frequent weeding, yields in 2000 ranged from 2.21 to 4.72 t ha^{-1} (Table 1).

- The potential level of yield farmers could have achieved with currently grown cultivars, nutrient management and other agronomic practices was over 3 t ha^{-1} on 85% of the fields used in this study.
- At 3.42 t ha^{-1}, the mean yield on low fields was significantly lower than those on upper (3.96 t ha^{-1}) and medium (4.04 t ha^{-1}) toposequence positions respectively ($P \leq 0.05$).
- The mean potential yield gap (weed free – unweeded) was lowest in Rajabari that also had a higher number of fields with yield gaps of below 0.5 t ha^{-1}. Across all villages 54% of yield gaps were between 0.5 and 1 t ha^{-1} and at 26% of fields the gap was over 1 t.

- The yield that farmers gained through current levels of weed management varied from 0.33 t ha^{-1} for fields at Rajabari to 0.47 t ha^{-1} at Nachole. On average farmers gained more by weeding low toposequence fields (0.51 t ha^{-1}) than by weeding those at upper (0.35 t) or medium (0.37 t ha^{-1}) positions ($P \leq 0.05$).
- At 65% of the sites studied, farmers' existing weed management gained up to 0.5 t ha^{-1} while the return to farmer weeding was greater elsewhere.
- There was no significant difference between villages or toposequence positions in the mean yield which could be achieved in the 2000 season when additional weeding was applied to farmer weeded plots. This yield gap due to weeds under existing levels of management varied from 0.29 t ha^{-1} at Rajabari to 0.47 t ha^{-1} at Nachole. **More than 0.5 t ha^{-1} could be gained by additional weeding at 34% of the sites studied.**
- Yields were higher in 2001, particularly on the lower and mid toposequence positions. There were significant yield differences between villages in 2001 which also differed in extent across toposequence. Averaging across villages and toposequence, the application of additional fertiliser (86 kg ha^{-1} N, 84.5 P, 80 $K_2 0$ and 20 S) did not significantly increase yield (mean increase = 0.32 t /ha, P =0.38) whereas additional weeding and fertiliser elevated yield by 0.76 t/ ha P< 0.001). The greatest yield increase was seen at low toposequence with a yield increase of 0.9 t/ha as a result of improved weeding and fertiliser.

A summary of the effects of weed and nutrient management on grain yield for T-*aman* 2000 and 2001, *boro* and *aus* 2001 in two villages in Comilla are shown in Figures 2 and 3. In 2000 the average yield potential of the T-*Aman* crop in Chowara, recorded from plots which were kept weed free for 50 days after transplanting, was 60% greater than observed in Paruara. This is thought to be largely a reflection of two different soil types which are free draining in Paruara but allow water to be retained in paddy fields in Chowhara.

- Comparison of crop performance on unweeded and intensively weeded plots showed a significantly different potential greater yield gap due to weeds (P <0.001) in Paruara of 0.81 t compared to 0.58 t ha^{-1} in Chowara.
- As is shown in Figure 1, a broad distribution of potential yield gaps was observed across the two villages with 67% of farms represented by a yield loss due to weeds of 0.2 to 1 t ha^{-1}. A yield gap of more than 1 t ha^{-1} was observed at 23% of farms.
- The yield gained by farmers' own weed management practiceses (farmers yield less unweeded plot yield) averaged 0.3 t ha^{-1} in both villages ranging from near zero to 1 t ha^{-1}.
- The difference between yields under farmer management, and on plots which were intensively weeded, indicates a yield gap which could be closed by the use of additional weeding inputs, more efficient or more timely practices than are currently used. In the 2000 *aman* season this was on average 0.51 t ha^{-1} for farms in Paruara, significantly higher (P<0.001) than the 0.3 t ha^{-1} at Chowara. Overall 18 % of farms would have gained no more than 0.13 t by additional weeding while for 58% the losses with current practices range from 0.13 to 0.63 t ha^{-1}. In both villages some **30% of farmers could save losses of 0.5 t ha^{-1} or more by investing in additional weeding.**
- In T-a*man* 2001, yields again differed between the two villages but no significant gains were accrued by additional nutrients or weeding.
- As expected the yield potential of the *boro* season, when farmers have the opportunity to manage irrigation water more closely than in the T-*aman* when they largely depend on rainfall, was show to be greater than in the T-*aman* (Figure 3). Yields were significantly higher on the water retentive soils in Chowhara (P<0.001) where the mean yield gain from additional weeding was 0.7 t/ha (P<0.001). The corresponding yield gain in Puarara was 0.2 t/ha (P = 0.06).
- In contrast in the rainfed *aus* crop, yields were low and there was no significant difference between unweeded plots and those managed by farmers (n=10, P=0.1) Additional weeding gave a significant yield increase of 1.1 t/ha ((<0.01).

Figure 1. Effect of weeding and nutrient management on productivity of T-Aman rice in the Barind Tract in Bangladesh. Data are mean (+/- se) grain yield (14% moisture content).

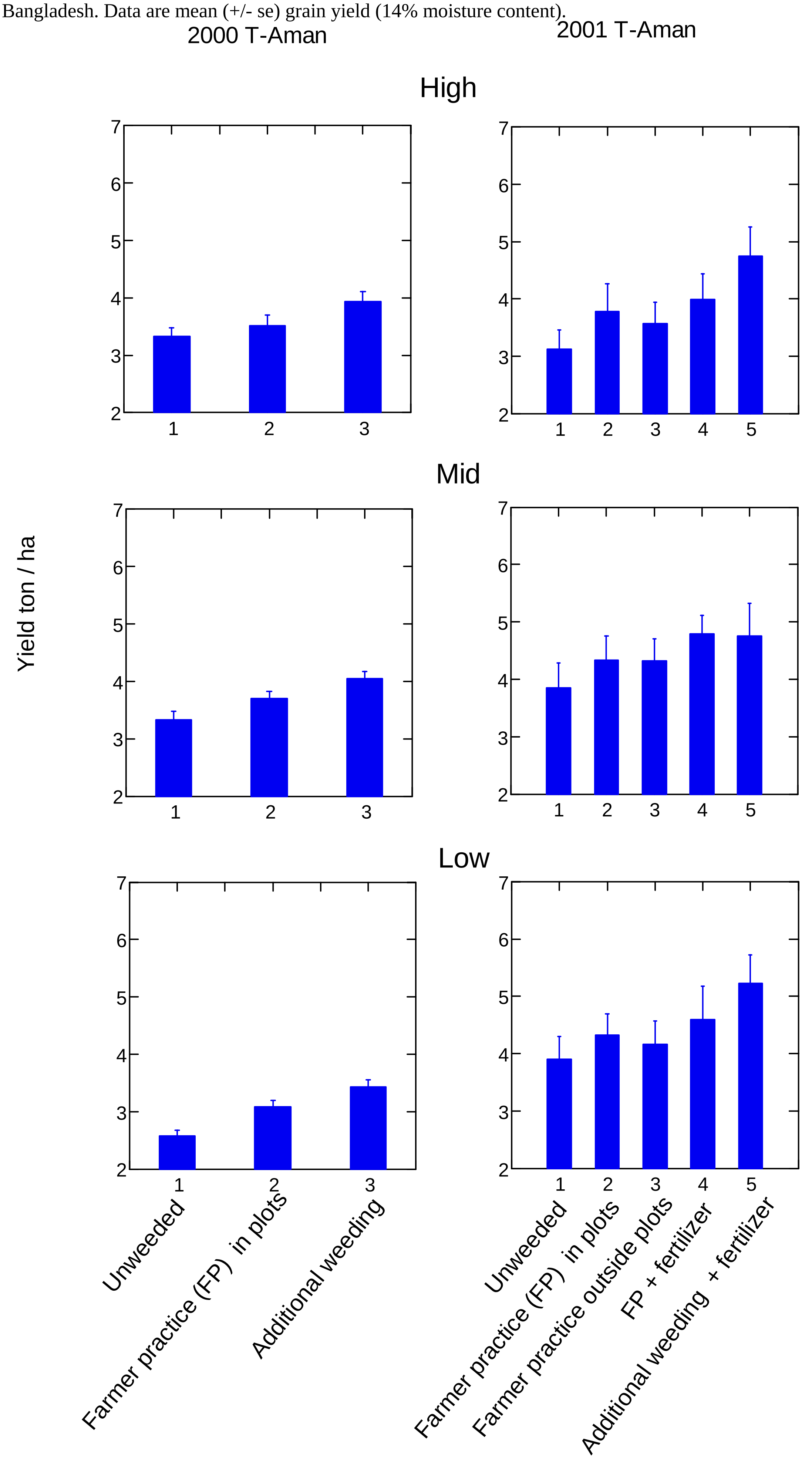


Figure 2. Yield of T.*Aman* rice on weed free plots and yield gaps due to weeds on unweeded plots, the yield gained by farmers weeding practice and, potential yield to be gained by additional weeding. Means for 20 fields in Chowara and Paruara villages, Comilla 2000. Ahmed *et al*., (2002).

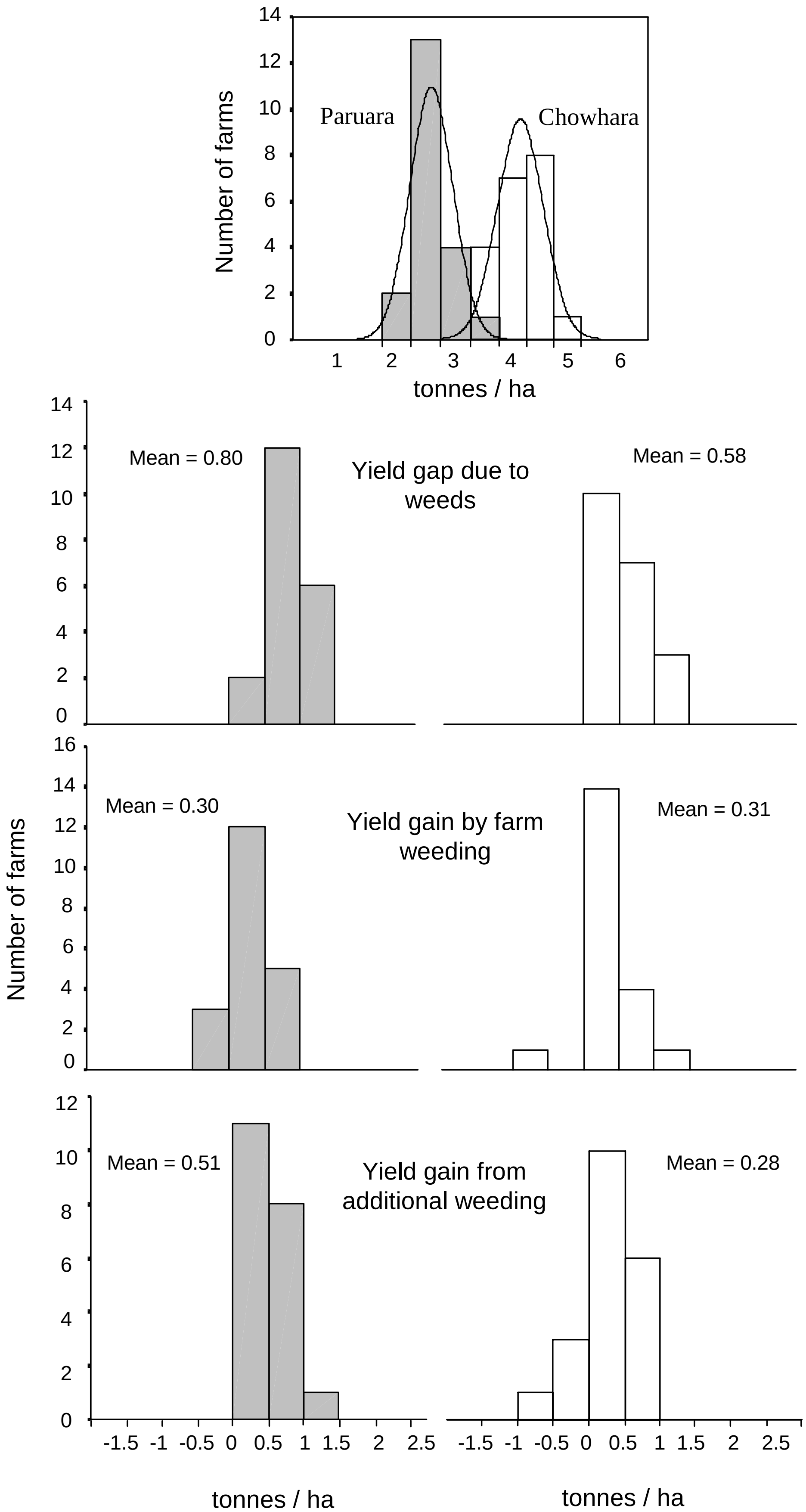
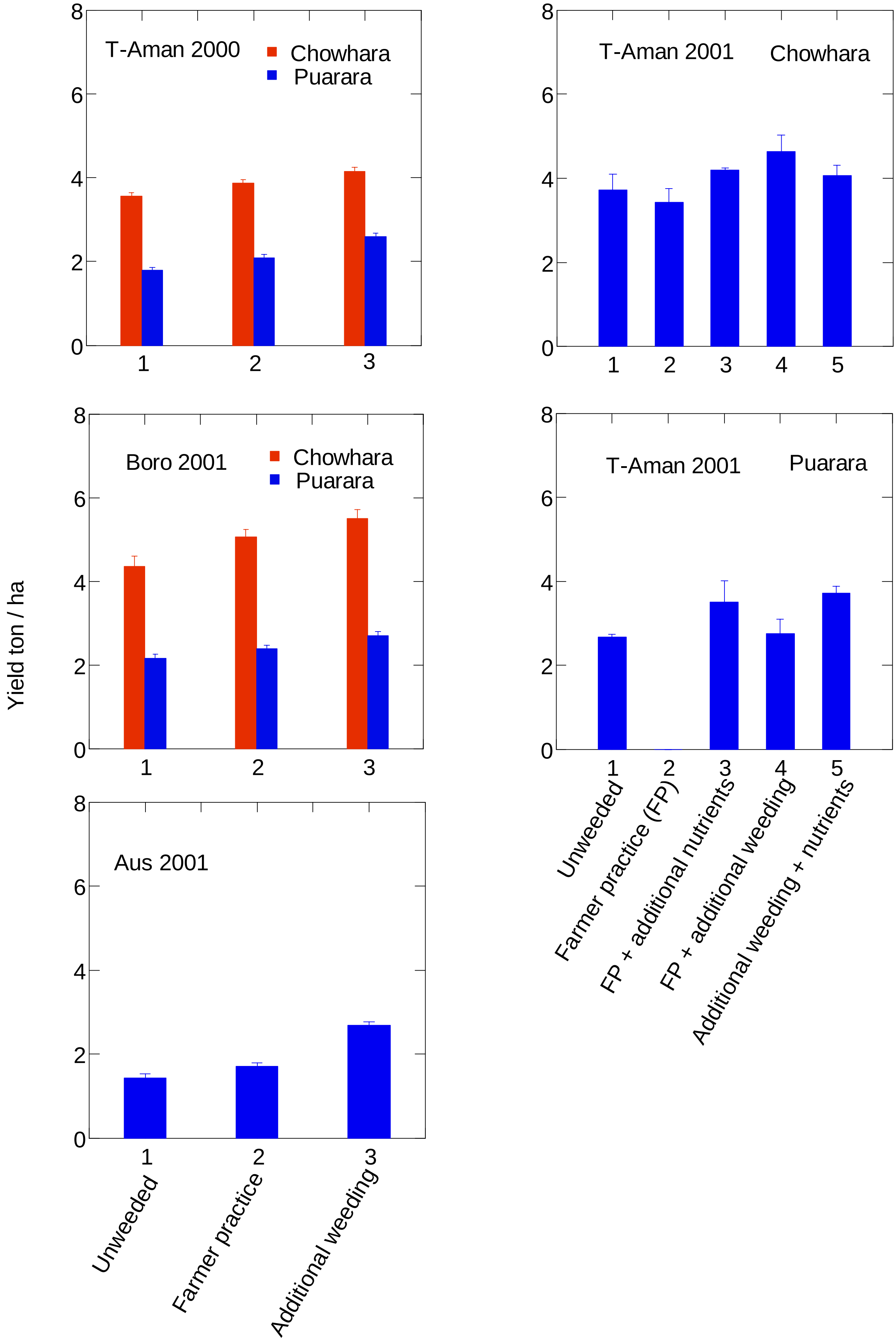


Figure 3. Effect of nutrient and weed management on yield (t ha^{-1}) of transplanted rice on-farmers' fields in *aus*, *boro* and *aman* seasons in Chowhara and Paruara villages, Comilla district.



Weed species inventories and identification of problem species: Focus group discussions in Rajshahi indicated that farmers perceived *Fimbrystylis miliacea* and *Cynodon dactylon* to be problematic weeds on upper toposequence land. In general fewer weeds were identified in the medium toposequence. In the lowland areas, *Paspalum distichum* was identified by all focus groups as problematic. These species were included among the five most abundant weeds observed at the yield gap trial sites (Table 2). *Fimbrystylis miliacea* was the most abundant species on all land types. Fields were infested by up to three potentially difficult to control rhizomatous grasses, *Cynodon dactylon*, *Paspalum distichum* and *Leersia hexandra* - these were all present on the lower toposequence. Based on experience elsewhere, these perennials, a number of other grasses including *Echinochloa* spp, and sedges, particularly *Cyperus difformis* could pose a threat to yield in a direct seeding system in which herbicides are used.

Table 2. Weed species inventory for the Barind Tract Toposequence, based on observations made on yield gap plots on farmers' fields in Rajabari, Tanore and Nachole.

Toposequence position		
Upper	**Medium**	**Lower**
The five most abundant species:		
Fimbristylis miliacea	*Fimbristylis miliacea*	*Fimbristylis miliacea*
Cyperus tenuispica	*Cyperus tenuispica*	*Paspalum distichum !*
Cyperus difformis !	*Paspalum distichum !*	*Cynodon dactylon !*
Cynodon dactylon!	*Cynodon dactylon !*	*Leersia hexandra !*
Paspalum distichum !	*Cyperus iria*	*Cyperus tenuispica*
Other widespread species:		
Alrernanthera sessilis	*Monochoria vaginalis*	*Paspalum distichum!*
Cyperus iria	*Alternathera sessilis*	*Monochoria vaginalis*
Monochoria vaginalis	*Eclipta prostrata*	*Ludwigia octovalvis*
Eriocaulon cinereum	*Hydrolea zeylanica*	*Sphaeranthus indicus*
Eclipta prostrata	*Marsilea minuta*	*Alternanthera sessilis*
Paspalum distichum!	*Sphenoclea zeylanica*	*Cyanotis axillaris*
Hedyotis corymbosa	*Aeschynomene indica*	*Cyperus iria*
Lindernia ciliata	*Nymphoides indica*	*Eclipta prostrata*
Ammania baccifera	*Ammania baccifera*	*Eriocaulon cinereum*
Pseudoraphis spinescens	*Ammania baccifera*	*Hedyotis corymbosa*
Sphaeranthes indicus		*Cyperus difformis*
Cyanotis axillaris		*Echinocloa colona!*
Cyperus rotundus!		*Aeschynomene indica*
Echinocloa colona!		*Ammania baccifera*
Fimbristylis dichotoma		*Lindernia ciliata*

! Indicates aggressive species that could become a problem under direct seeding without careful weed management.

A total of 28 weed species were observed at yield gap trial sites in Comilla (Table 3). A greater species diversity was present at Paruara. This may be associated with the three-crop system prevalent here or due to soil factors. Soils in Paruara are sandy and quick draining compared to Chowara. There is therefore less opportunity for weed suppression by standing water at Paruara.

Table 3. Inventory of weed species observed at Chowara and Paruara in T.*aman* rice.

Chowara	Paruara
Alternenthera phyloxeroides	*Alternenthera phyloxeroides*
Alternenthera sessilis	*Alternenthera sessilis*
Cyperus difformis	*Anoxopus compressus*
Cyperus flavirus	*Cyperus flavirus*
Cyperus iria	*Cyperus iria*
Desmodium trifolium	*Commelina bengalensis*
Echinochloa crus-galli	*Cynodon dactylon*
Echinochloa colona	*Cyperus difformis*
Eleocharis atropurpurea	*Desmodium trifolium*
Fimbristylis miliaceae	*Echinochloa crus-galli*
Hydrolea zeylanica	*Echinochloa colona*
Ludwigia octovalvis	*Eclipta alba*
Monochoria vaginalis	*Eleocharis atropurpurea*
Oplisma burmaniaii	*Fimbristylis miliaceae*
Phyllea nodiflora	*Hydrilla verticillata*
Pistia stratiotes	*Hydrolea zeylanica*
Scirpus mucronatus	*Ludwigiis octovalvis*
	Leptochloa chinensis
	Limnoplula trichophylla
	Lindernia anagallis
	Lindernia procumbens
	Monochoria vaginalis
	Oplisma burmaniaii
	Phyllea nodiflora
	Pistia stratiotes
	Rungia pictinata
	Salvinia natans
	Scirpus mucronatus

World-wide, at least 30 weed species which are associated with rice have now evolved resistance to one or more herbicides. These include a number of species or close relatives of the weeds listed above. Some widespread species have developed resistance elsewhere to herbicides which are sold in Bangladesh including cinosulfuron (Set Off) whose mode of action is to inhibit the enzyme acetolactate synthase (ALS) and butachlor (Machete) which inhibits long chain fatty acid biosynthesis and hence cell division in susceptible species. The most widespread problem occurs with the ALS inhibiting sulfonylurea herbicides, particularly bensulfuron-methyl to which resistance has developed on four continents in some key species including *C. difformis, Lindernia* spp. and *Monochoria* spp. Resistance has appeared following five to seven years continuous use of this herbicide. In many cases weed populations which evolve resistance to one sulfonylurea prove to be resistant to other herbicides in this group as well. Set Off (cinosulfuron) is being adopted in Bangladesh on farms where *C. difformis, Monochoria, Lindernia,* and *Scirpus* occurr. It is therefore highly likely that with continuous use resistance to cinosulfuron will develop in a number of species in Bangladesh. Butachlor (Machete) is also at risk. *Echinochloa crus-galli*, a widespread annual grass weed in Bangladesh, has evolved resistance to butachlor in both China and Thailand. Farmers, company representatives and pesticide dealers need to be made aware of the risk of weeds developing resistance to herbicides in Bangladesh and of appropriate resistance prevention and management strategies through which it should be possible to maintain the useful life of currently available herbicides. This issue has been discussed in more detail in the project working paper on herbicide adoption in Comilla (Riches *et al*., 2002).

Output 3: Persistence, dormancy and quantity of weed seeds in seed bank determined

Weed species response to cropping system and weed management: Previous work in Bangladesh has suggested that a greater weed burden occurs following crop establishment by direct seeding compared to transplanting. Work for this output was therefore directed at attempting to understand the effect that a change in rice establishment method, from transplanting to direct seeding, may have on weed abundance and species composition and how different weed control practices could be used to manage such changes. As direct seeding has yet to be adopted in *aman* rice in Rajshahi it was decided to use a long term experiment (LTE), including combinations of crop establishment and weed control practices for a rice/chickpea rotation, to examine possible effects on the weed flora. The LTE, which is on-going at Rajabari, was established by RLRRC on a medium toposequence position during *aman* 1999. With the inception of this project, modifications were made to the trial for 2000 as described under output 4 and the current treatment combinations have now run for three seasons. In 2000 data on weeds was collected by "weed group" (broadleaf, grasses and sedges). Detailed monitoring of weed number and biomass by species was undertaken in 2001 and in 2002. A quantitative estimate of the weed seedbank, as effected by cropping practice, is on seed pan work. This began at Rajabari in February 2002 and involves counting weed seedlings emerging from samples of soil taken from plots following chickpea harvest in 2001 and 2002. This a time consuming exercise, due to the need for inclusion of sufficient samples for statistical validity and the need to allow sufficient time for the seedbank in the soil samples to be exhausted. Although work on dormancy flux in seed populations of individual species could help to explain the rate of change in abundance and their persistence it was decided not to pursue this. The necessary laboratory facilities and expertise were not available at the Rajshahi BRRI Sub-station, due to staff undergoing Ph.D training away from station and to set up such work would have detracted from an already full and complex project work programme. It was considered that the information on the bigger picture of weed population trajectories as effected by cropping practice, useful for making recommendations to farmers on weed management, could be obtained from the seed bank study.

Weed responses

Table 4 shows the rank abundance of weed species in the soil from seed bank evaluation. Thirty four species were present within the rice landscape (fields, bunds and waste land) on the basis of farm scouting although only 22 (including three unidentified species) were recorded from soil cores. Whilst the biodiversity of the weed flora may be incompletely reported in Table 4 and analysis will be supplemented by further data subsequently, the soil seed bank reflected a diversity of species characteristic of rainfed rice with a predominance of sedges (*Fimbrystylis miliacea*, *Cyperus difformis* and *C. iria*). The notable grass weed was *Echinochloa colona*. Species characteristic of upper toposequence rainfed rice were also represented (*Rotall indica, Lindernia* spp).

Figure 4 illustrates the weed abundance (dry biomass 28DAS/DAT) within plots in relation to crop establishment method (2002 data). These data reflect long term potential changes in the weed flora that may result from changes in crop establishment method. Transplanting and flooding halved mean weed biomass (28DAS/DAT) in comparison to direct seeding (55 g /m^2 versus 107 g/m^2) whereas in direct seeded oxadiazon treated plots biomass increased to 132 g/m^2. Oxadiazon was effective in reducing weed abundance of most species but not *Paspalum distichum Cyperus iria* and *Eclipta prostrate.* These species particularly *P. distichum* contributed to the increase in weed biomass observed in oxadiazon treated plots. *Alternaria sessilis* and

Cyanotis axillaris were only recorded in direct seeded plots. Further detailed analysis over seasons will be conducted prior to journal publication.

Supporting information on two years monitoring of weeds in the LTE, and conclusions to date on the impact of crop management practice are reported under output 4.

Table 4. The relative abundance of weed species present in the soil seed bank in 2000, prior to the start of the 2000 cropping season of the LTE. A standard volume of soil was sampled from plots across the whole trial and the number of seedlings emerging in seed pans under aerobic or saturated soil conditions were subsequently counted over one month. Data for individual species are presented in rank order from the primary assessment. A subsequent assessment after soil stirring will be reported separately.

	Species	Aerobic	Species	Saturated
1	Fimbristylis miliacea	22.97	Dopartium junceum	14.94
2	Dopartium junceum	13.43	Cyperus difformis	14.11
3	Cyperus difformis	11.31	Fimbristylis miliacea	9.38
4	Cyperus iria	8.57	Rotala indica	7.96
5	Unknown 1	6.18	Eriocaulon cinereum	7.51
6	Hedyotis corymbosa	5.12	Unknown 1	7.21
7	Echinocloa colona	4.51	Cyperus iria	5.71
8	Unknown 2	4.51	Ludwigia octovalvis	4.65
9	Ammania baccifara	3.53	Cyperus tenuispica	4.50
10	Lindernia ciliata	3.00	Unknown 2	4.43
11	Sphaeranthus indicus	2.83	Lindernia ciliata	3.38
12	Cyperus tenuispica	2.65	Eclipta prostrata	3.30
13	Eriocaulon cinereum	2.56	Ammania baccifara	2.85
14	Rotala indica	2.47	Echinocloa colona	2.70
15	Ludwigia octovalvis	2.03	Sphaeranthus indicus	2.63
16	Unknown 3	1.50	Altenanthera sessilis	2.48
17	Monochoria vaginalis	1.15	Lindernia sp	0.83
18	Lindernia sp	1.15	Monochoria vaginalis	0.75
19	Alrenanthera sessilis	0.18	Unknown 3	0.38
20	Paspalum distichum	0.18	Hedyotis corymbosa	0.30
21	Aeschynomene indica	0.09		
22	Ischaemum rugosum	0.09	Aeschynomene indica	0.00
			Cyanotis axillaris	0.00
23	Cyanotis axillaris	0.00	Cyndon dactylon	0.00
24	Cyndon dactylon	0.00	Cyperus rotundus	0.00
25	Cyperus rotundus	0.00	Echinocholoa crus gall	0.00
26	Echinocholoa crus gall	0.00	Fimbristylis dichotoma	0.00
27	Eclipta prostrata	0.00	Hydrolea zeylanica	0.00
28	Fimbristylis dichotoma	0.00	Ischaemum rugosum	0.00
29	Hydrolea zeylanica	0.00	Ludwigia adscendens	0.00
30	Ludwigia adscendens	0.00	Marsilea minuta	0.00
31	Marsilea minuta	0.00	Nymphoides indica	0.00
32	Nymphoides indica	0.00	Paspalum distichum	0.00
33	Pseudoraphis spinesc	0.00	Pseudoraphis spinesc	0.00
34	Sphenoclea zeylanica	0.00	Sphenoclea zeylanica	0.00

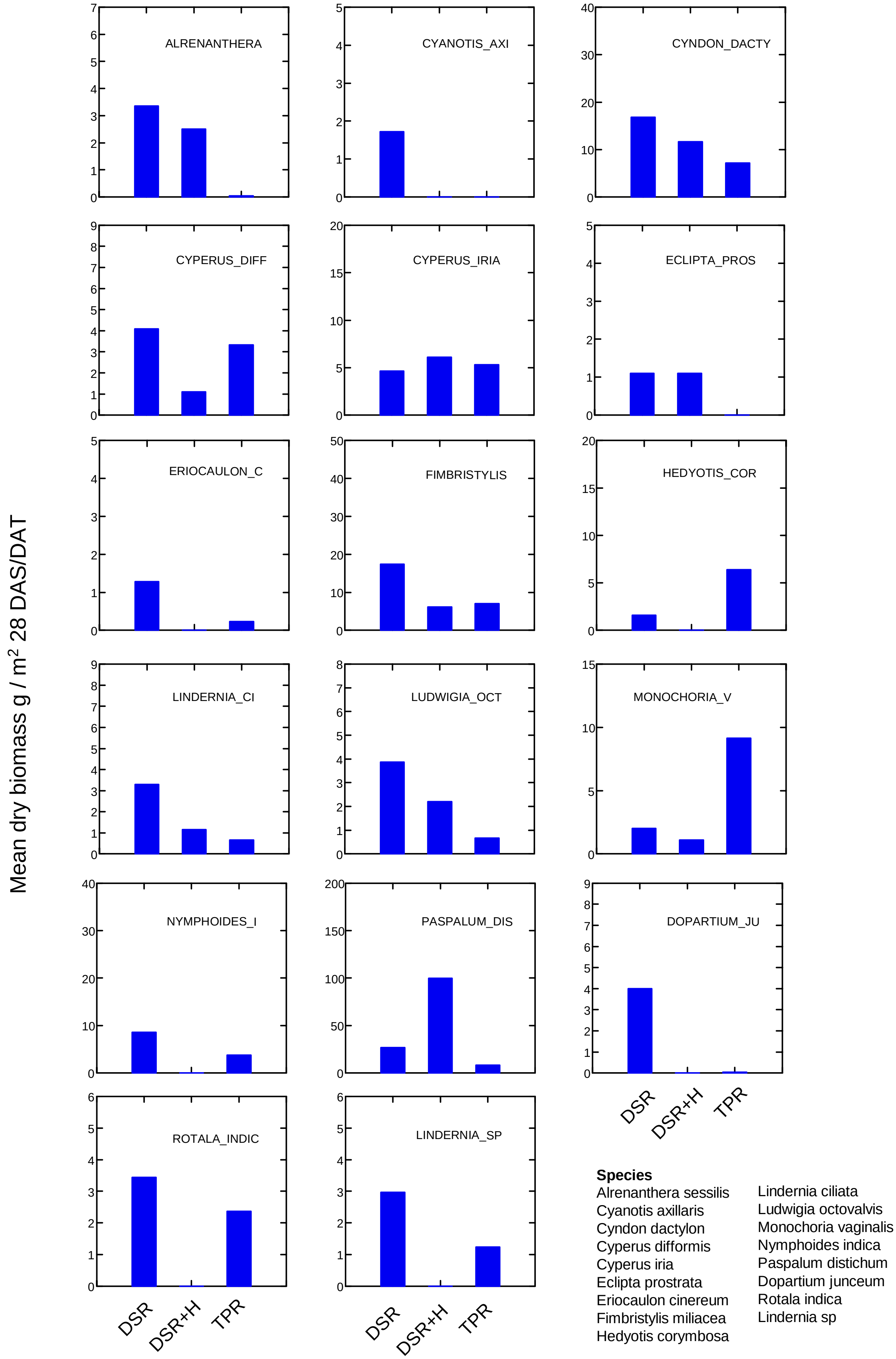


Figure 4: Weed abundance at 28 DAT/DAS. Data meaned across fertiliser/variety treatmeants.

Output 4: Integrated weed management strategies to reduce the build-up of weed populations by regulation of soil seed banks which are appropriate to the farming system and cultural context of each area studied developed.

Investigations at Rajshahi: Fully replicated trials have been undertaken on land rented from farmers at the Rajabari key site of RLRRC in *aman* 2000, 2001and 2002 as follows:

- Long term experiment on the medium toposequence position - comparing rice yield and weed population response to different rice crop establishment, nutrient management and weeding practices. The aim of the trial is to optimise the productivity of system in which *aman* rice is immediately followed by *rabi* chickpea;
- Weed control practice trial on both high and medium toposequence positions - Evaluation of weed management for direct seeded rice had been initiated during 1999 *aman* by BRRI/RLRRC. Data from this season was initially analysed by the current project before a modified trial was conducted in 2000 and 2001. Timing of pre-plant tillage and in-crop weed control by herbicides, mechanical and hand weeding were compared;
- Rice and chcikpea pre-plant priming trial – Overnight soaking of rice and chickpea seed has been demonstrated as a method for improving crop establishment by the DFID Plant Science Research Programme including work in Rajshahi district by project R7540. A proposed additional benefit of priming is an earlier harvest. If the rice harvest could be advanced, by even a few days, by priming this may increase the window of opportunity when soil is moist enough for planting a *rabi* crop following a direct seeded, short duration rice cultivar. Priming was therefore evaluated in two seedbed conditions for two seasons as a possible component of the direct seeding system.

The Long term experiment (LTE): A more detailed background to the trial, methods and summary of results for 2000-01 *aman and rabi* seasons has been reported in Mazid *et al* (2001). This on-going trial uses a split-strip-split plot design, with cropping system as the main plots, nutrient strips within these, split for rice variety within each replicate. In summary the treatments (Figure 5) are:

Cropping systems

Transplanted aman rice - *rabi* fallow – *aus* fallow.
Soil puddled prior to transplanting, hand weeding only.

Direct seeded aman rice (conventional weed man.) – *rabi* chickpea – *aus* fallow.
Soil ploughed prior to seeding (due to heavy early rain in 2000 was puddled and sown with sprouted rice seed); hand weeding only. Chickpea broadcast and incorporated by cross ploughing, no weed control.

Direct seeded aman rice (in-crop herbicide) – *rabi* chickpea – *aus* mungbean if moisture allows. As above but in-crop weed control by pre-emergence application of Ronstar (oxadiazon).

Varieties

Swarna (GD 140 – 145 d); widely grown by farmers
BRRIdhan 39 (GD 120 - 125 d); recently introduced by BRRI

Nutrient

- Control (PK)
- NPK
- ½ NPK + ½ FYM
- DAP (basal) + Guti Urea (GU - granules) at 30 DAS / 10 DAT

Results for wet season 2000 rice crop and rabi season chickpea 2000-2001:

Table 5. **Analysis of Variance for Rice Growth**

Source	Tillers m^{-2}	Panicles m^{-2}	Height (cm)	Yield (t ha^{-1})
System (S)	**4.42_**	**4.03**	**1.48**	**1.94**
Nutrient (N)	**29.4 *****	**27.5 *****	**76.9 *****	**24.8 *****
S x N	**2.41**	**2.08**	**3.21 ***	**2.20**
Variety (V)	**10.6 *****	**1.70**	**78.8 *****	**204.0 *****
S x V	**3.32**	**3.36**	**0.77**	**18.8 *****
N x V	**1.10**	**0.93**	**0.54**	**1.65**
S x N x V	**0.54**	**0.42**	**0.53**	**1.64**

Figure 5. TPR - DS Rice / Chick Pea Cropping Systems in LTE

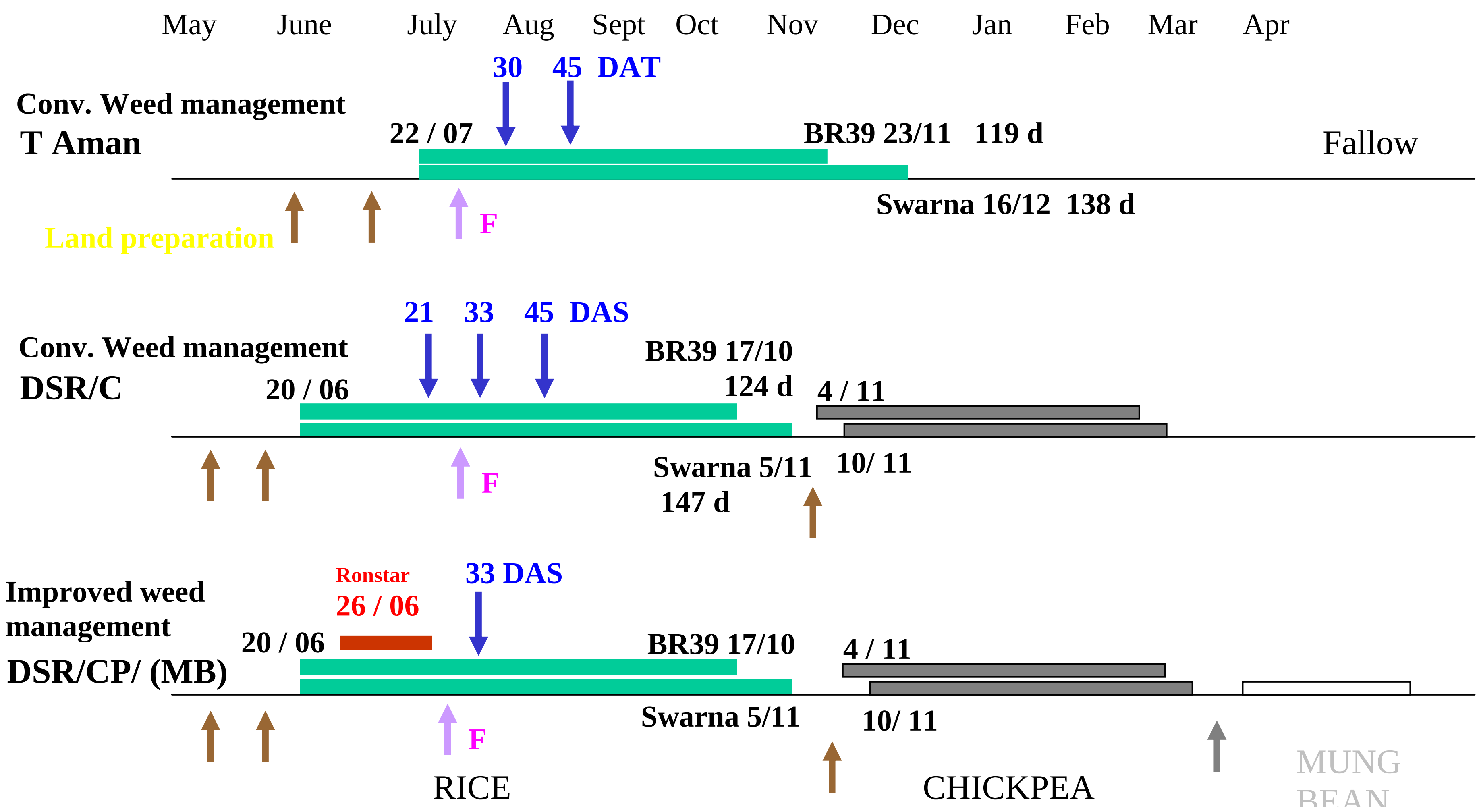


TABLE 6. **SYSTEM BY VARIETY INTERACTION FOR RICE GRAIN YIELD (T/HA)**

	BRRI dhan 39	Swarna	Mean
TPR	2.67	3.23	2.95
DSR	1.73	2.96	2.35
R'star	1.77	3.60	2.68
Mean	2.06	3.26	2.66

TABLE 7. **CHICKPEA RESPONSES AFTER RICE 2000/2001**

	After BRRI dhan 39	After Swarna
(a) Phenology		
Sown	4 Nov	10 Nov
Emerged	8 Nov	17 Nov
(b) Plant Stand		
Day 16	34.2	30.6
Day 31	26.4	21.9
Day 108	22.9	17.3
(c) System and Rice Variety Effects on Chickpea Plant Stand at day 108		
Handweeded DSR	22.8	15.1
Ronstar DSR	23.0	19.4

Table 8. *Weed Biomass Remaining at Harvest*

System	g m^{-2}
T-*aman* + hand weeding	75
DSR + hand weeding	229
DSR + Ronstar	141

System effect significant P > 0.0162

Table 9. Treatment Effects on Total Weed Biomass for Hand Weeded Direct Seeded and Transplanted Rice Averaged Across Nutrient Treatments.

Time DAS/DAT	g m2	Significance
21 DAS	24	
30 DAT	30	<0.095
45 DAS	24	
45 DAT	31	<0.068
DS Harvest	228	
TP Harvest	75	<0.023

Table 10. **Interaction Effect of Variety and Crop Establishment Method on Weed Biomass ($g\ m^{-2}$) at Harvest.**

System	Cultivar	Weed g m2	Significance
DS	BR39	210	
	Swarna	246	<0.095
TPR	BR39	87	System x Var.
	Swarna	63	

Table 11. Effect on Nutrient Management on Weed Biomass at 33 Days after Rice Establishment by Direct Sowing.

Nutruent treatment	Weed g m2	Significance
Control	17	
NPK	23	<0.0047
½ NPK / FYM	19	
DAP/K/GUTI	25	

Analysis for aman *2001 and* rabi *2002*

Table 12: Treatment effects on rice yield

Treatment	*Yield t ha^{-1}*	*S.E.M*
Variety		
BRRI dhan 39	*2.58*	
Swarna	*2.83*	*0.05*
Nutrients		
PK	*2.15*	
NPK	*3.05*	
1.5(NPK+FYM)	*2.54*	
DPA+K+GUTI-2	*3.07*	*0.075*
Cropping system		
TPR - fallow	*2.355*	
DSR – CP (hand weed)	*2.767*	
DSR – CP (herbicide)	*2.999*	*0.063*
Variety by Cropping System		
BRRI dhan 39 - TPR	*1.92*	
BRRI dhan 39 – DSR-CP (hand weed)	*2.80*	
BRRI dhan 39 – DSR-CP (herbicide)	*3.02*	
Swarna - TPR	*2.79*	
Swarna - DSR-CP (hand weed)	*2.73*	
Swarna - DSR-CP (herbicide)	*2.97*	*0.089*

Table 13. Effect of treatments on weed biomass in unweeded areas at 45 DAS/DAT 2001 – significant effects from AVOVA.

Treatment effect	ANOVA significance level			
	Grass	Sedge	Broadleaf	Total
Cropping pattern	0.06	<0.01	<0.001	<0.05
Nutrient	0.07			<0.001
Nut. X crop				<0.01
Variety		<0.05		
Var. x Nut.				
Var. x crop		<0.01		
Var. x crop x Nut				0.06

Table 14: Mean total weed biomass at 45 DAS/DAT ((log+1) m-^{2}

Treatment		Biomass	S.E.M
Variety			
BRRI DHAN 39		2.182	
Swarna		2.191	0.0223
Nutrient			
PK		2.110	
NPK		2.176	
1.5(NPK+FYM)		2.173	
DAP+K+GUTI-2		2.287	0.0316
Cropping Pattern			
TPR - fallow		2.127	
DSR – CP (hand weed)		2.455	
DSR – CP (herbicide)		1.977	0.0273
Fertiliser by Cropping Practice			
PK	*TPR - fallow*	2.022	
PK	*DSR – CP (hand weed)*	2.404	
PK	*DSR – CP (herbicide)*	1.903	
NPK	*TPR - fallow*	2.223	
NPK	*DSR – CP (hand weed)*	2.381	
NPK	*DSR – CP (herbicide)*	1.923	
1.5(NPK+FYM)	*TPR - fallow*	2.134	
1.5(NPK+FYM)	*DSR – CP (hand weed)*	2.523	
1.5(NPK+FYM)	*DSR – CP (herbicide)*	1.861	
DAP+K+GUTI-2	*TPR - fallow*	2.128	
DAP+K+GUTI-2	*DSR – CP (hand weed)*	2.510	
DAP+K+GUTI-2	*DSR – CP (herbicide)*	2.222	0.0547

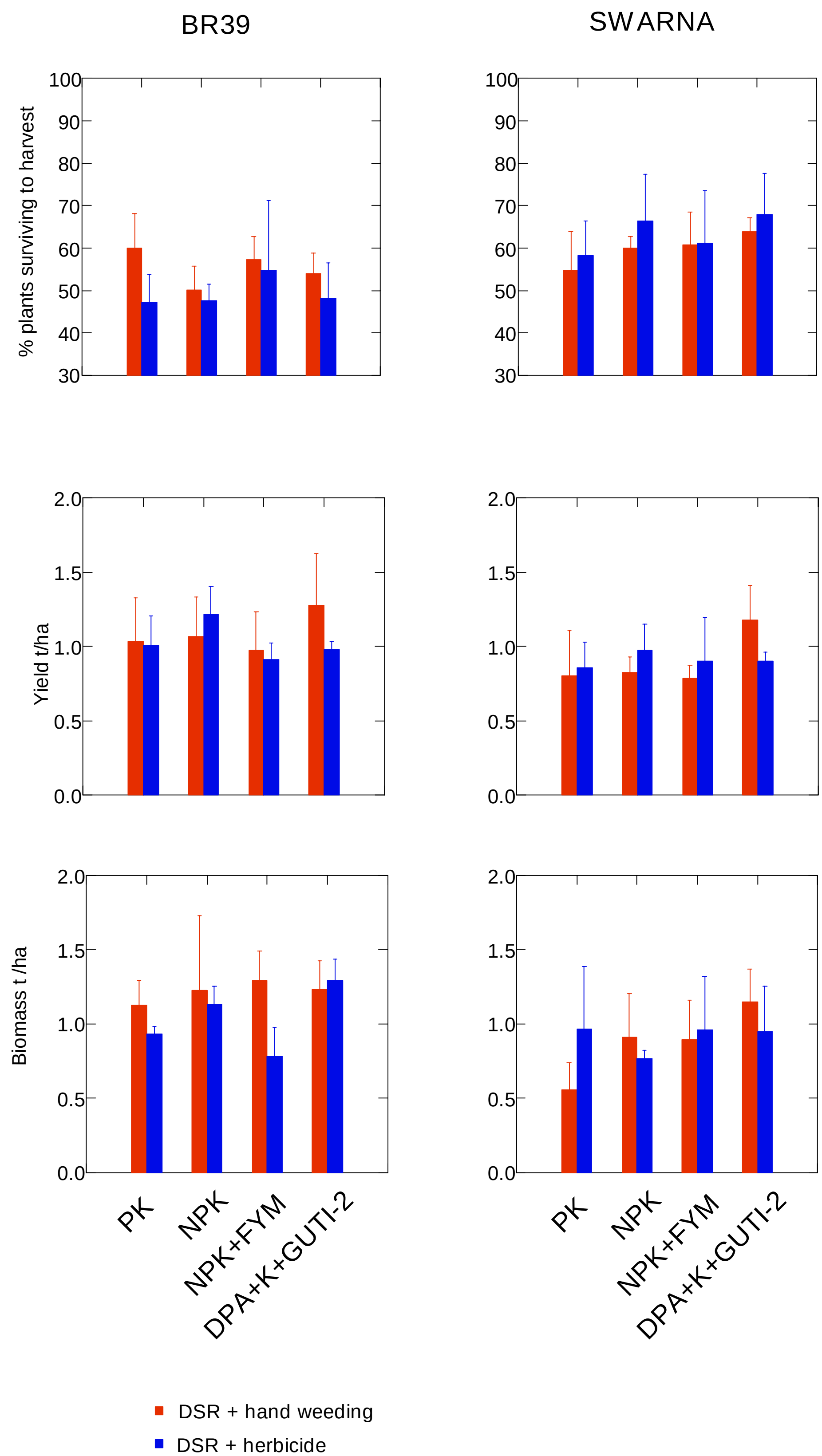


Figure 6: Effect of aman rice nutrient and weed management on survival, grain yield and aerial biomass of a subsequent chickpea crop (2001-02).

The above results demonstrate that clear system effects and interactions between cropping and weed management practice became established after two seasons into this trial.

Comparison of yields over three seasons.

Figure 6 a-c show yield components (tillers / m^2 at peak tillering, and panicles / m^2 at anthesis) and yields (filled grain / ha) of SWARNA and BRRIdhan39 in relation to crop establishment. In 2001 and 2002, SWARNA outyielded BRRIdhan39 in both tiller and panicle number under direct seeding and transplanting with the exception of tiller number in 2002). In 2000 there were no significant differences between varieties in tiller or panicle number and yields of BRRIdhan39 were highest (2.85 t /ha) from direct seeded plots, similar yields being obtained with SWARNA regardless of method of establishment.In 2002 the highest grain yield was obtained in DSR plots treated with oxadiazon sown to SWARNA and equivalent yields were obtained with BRRIdhan39 in all three systems. A similar pattern of response was observed in 2001 in relation to crop establishment for SWARNA whereas transplanted BRRIdhan39 gave least yield. Contrastingly transplanted BRRIdhan39in 2000 was superior in yield to DSR.

In all three seasons (2002 data only shown in Figure 6 d) yield of unfilled grain was highest in BRRIdhan39 and dependent on crop establishment method. SWARNA exhibited higher grain filling which was not dependent upon establishment method.

CONCLUSIONS AND IMPLICATIONS

1. There were significant effects of cropping system, especially in critical timings in rice and its consequences for success in the chickpea crop.
2. Flowering was later in SWARNA and with transplanting. On average, grain fill duration was similar over varieties, but was reduced by transplanting, especially for BRRIdhan39.
3. Nutrient application (NPK or DAP-K-Guti Urea) increased tiller and panicle number, plant height and grain yield. Tillers m^2 were lower with inadequate nutrients, especially in transplanting. Plant height was also reduced with inadequate nutrients, but especially in hand-weeded direct seeding. Tiller and panicle numbers were reduced in transplanting, especially in BRRI dhan 39 which was shorter than Swarna.
4. In 2000 Swarna yielded 1.2 t/ha more than BRRI dhan 39, whose yield was much lower in the direct seeding treatments. Untimely rain at flowering of BRRI dhan39 in the direct seeded treatments is believed to have reduced its spikelet fertility, resulting in fewer filled grains there. However, in 2001, although BRRI DHAN 39 performed poorly when transplanted, it contributed to increased rice productivity under direct seeding.
5. Swarna outyielded BRRI DHAN 39 in 2001 and 2002 and highest rice yields were obtained by direct seeding with early post-emergence application of oxadaizon.
6. In the 2000 wet season, late rains favoured the performance of, and delayed the establishment of chickpea, until after the harvest of Swarna. Any potential advantage from harvesting BRRI dhan 39 days earlier for timely chickpea establishment was lost in this season. In 2001-2 chickpea yields were generally higher following BRRI DHAN 39 compared to Swarna
7. Of concern was the decline in chickpea stand with age, perhaps reflecting an increased incidence of *Botrytis*. It may be necessary to replace chickpea with linseed or mustard in alternate years to reduce the build-up of sclerotia in the soil.
8. Analysis of weed biomass in unweeded plots enables assessment of the impact of agronomic factors on weed responses and the potential for weed species shifts. Results show that in both seasons greater weed biomass developed in rice established by direct seeding than under transplanting. Direct seeding increased the weed biomass at 45 DAS/T and that responses were fertiliser dependent. Overall the most weed biomass was present with the use of DAP+K+GUTI-2. When herbicide was used for weed control in direct seeded plots, weed biomass was least under all fertilizer treatments except DAP+K+GUTI-2. In transplanted plots and direct seeded plots not treated with Ronstar, the rank order of biomasss was sedge > grass > broadleafed weeds. The use of Ronstar

changed the ranking : grass > sedge > broadleafed weeds. In 2000/2001 seasons there was evidence that BR39 was more effective in suppressing sedge weeds, there being less weed biomass under BR39 than Swarna.

9. This research should be continued in order to permit long-term changes in nutrient availability, weed succession and crop performance to be expressed and understood. Such changes have important consequences for system performance and sustainability, and for farmer livelihood. The trial demonstrates clearly that weeds will build up under direct seeding, unless this is accompanied with a change in weed management practice – herbicide use has the potential to facilitate farmer adoption of direct seeding by overcoming the weed constraint.

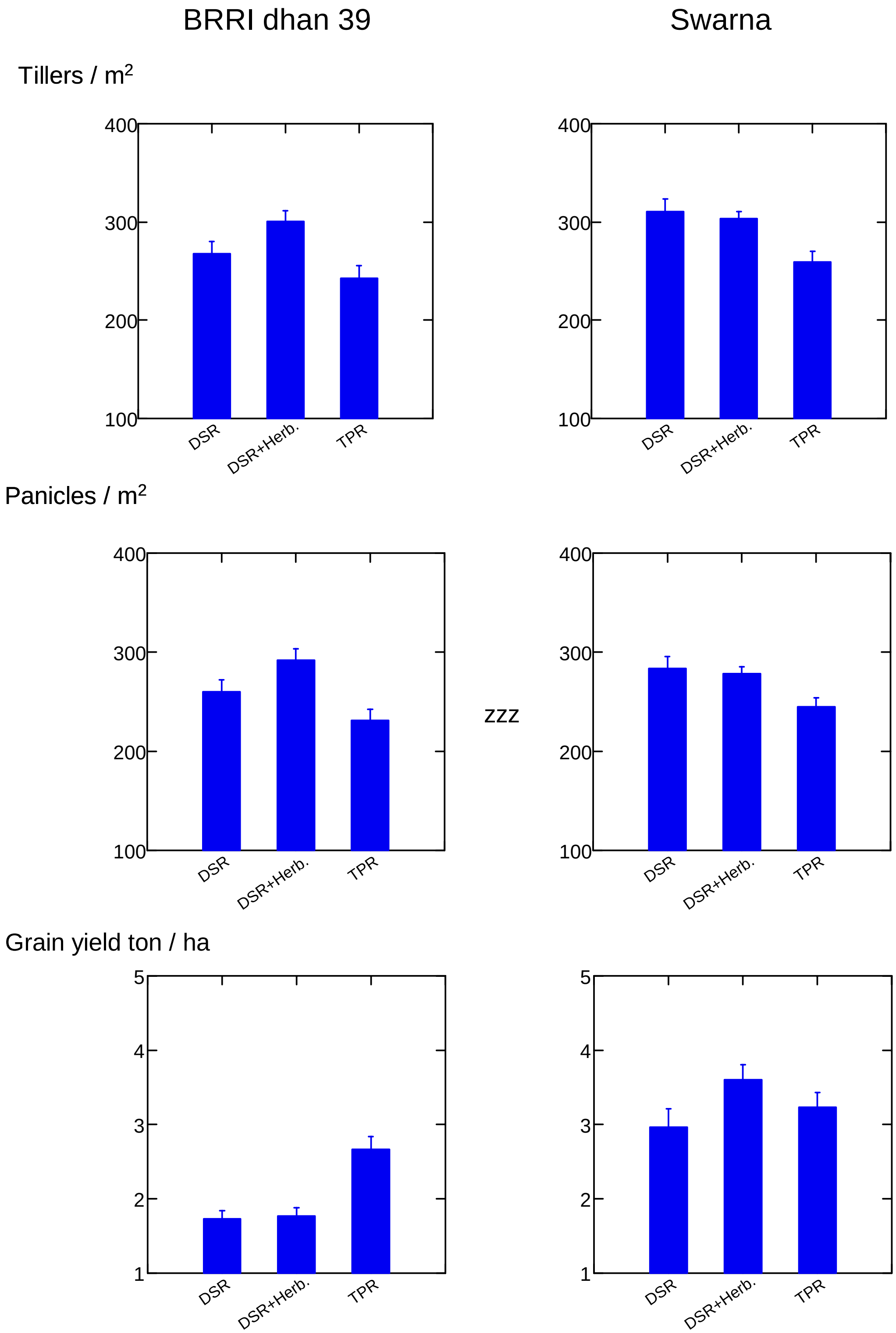


Figure 6 a) Tillers, panicles / m^2 and grain yield - Season 2000

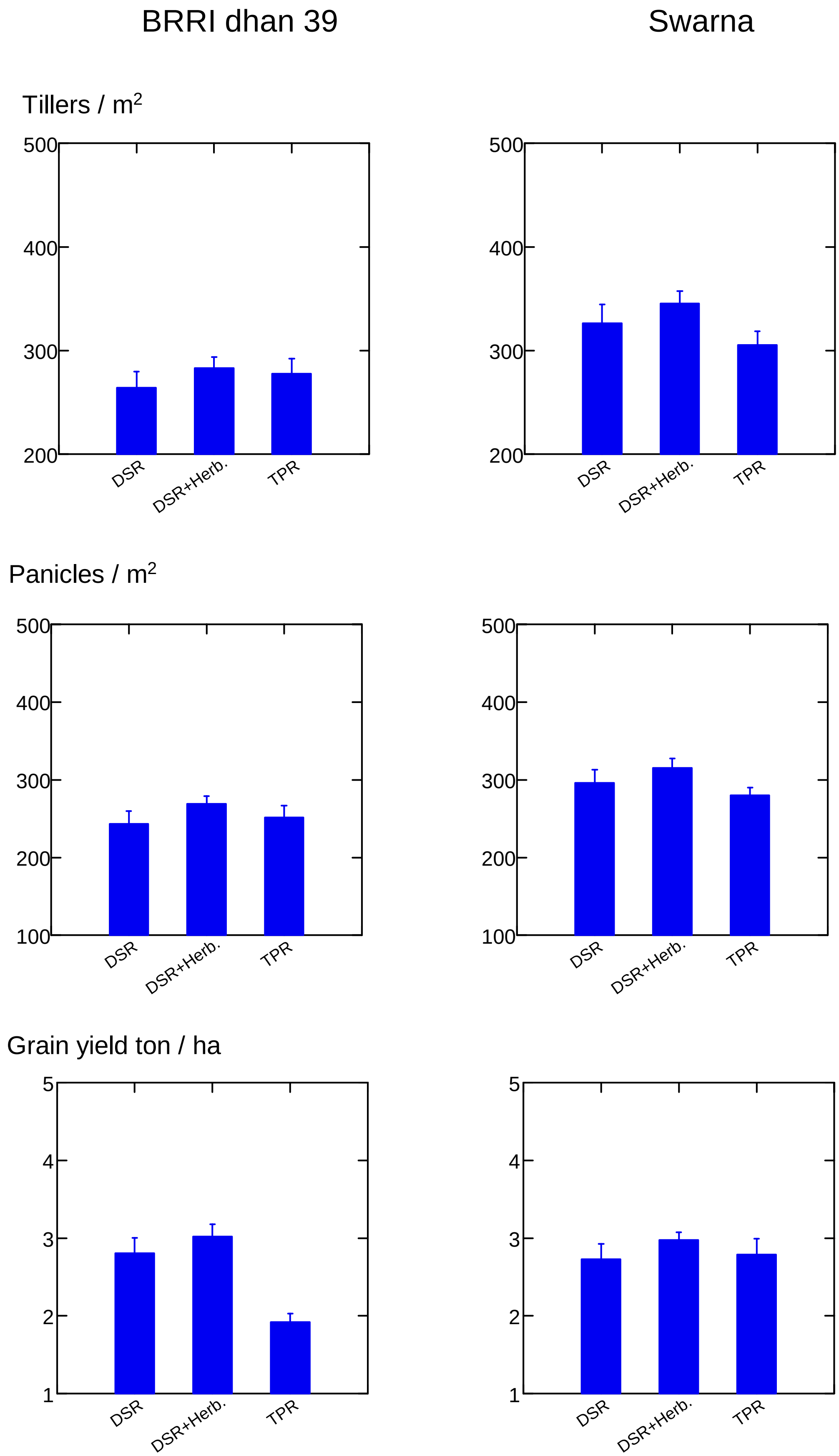


Figure 6b) Tillers, panicles / m^2 and grain yield - Season 2001

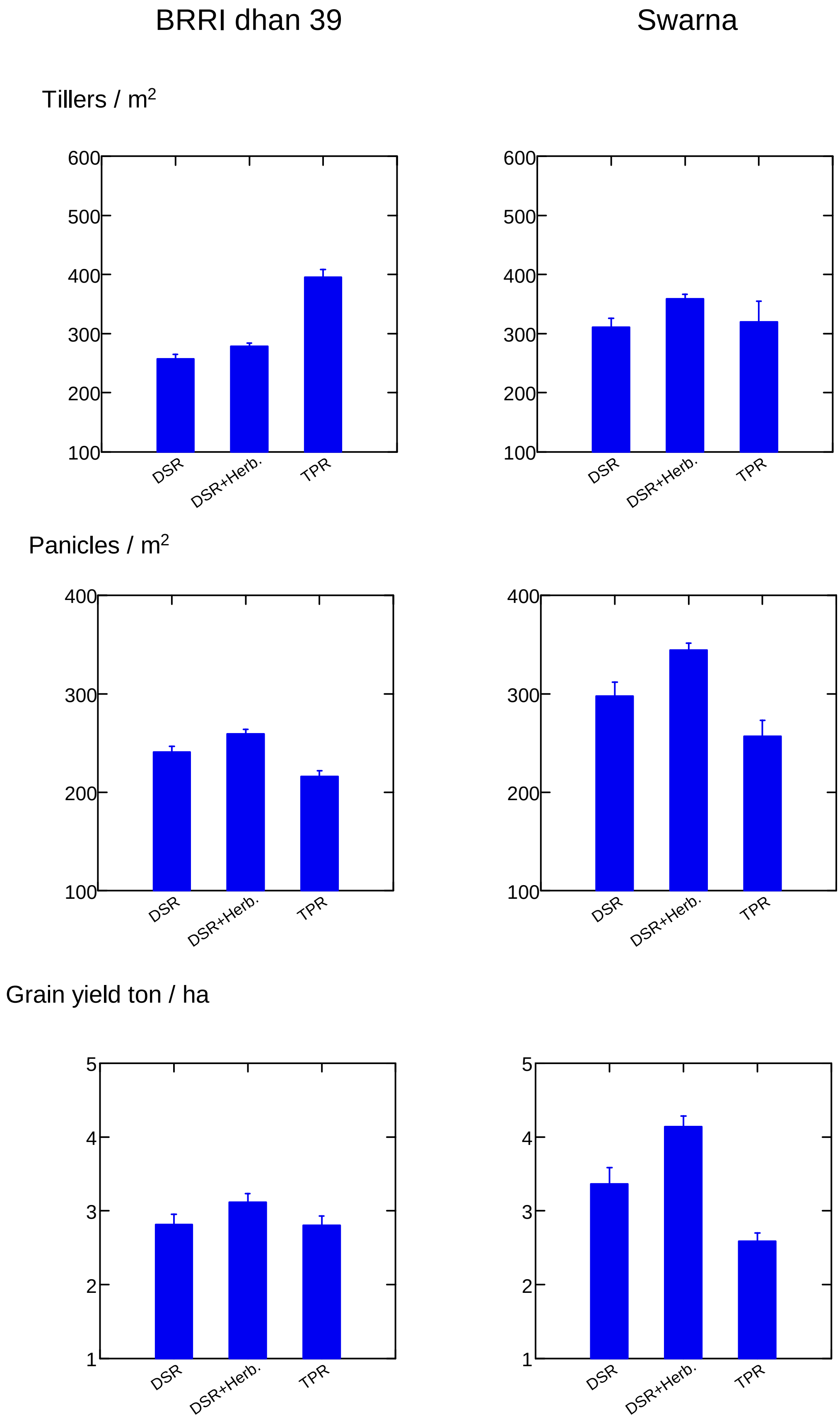


Figure 6 c) Tillers, panicles / m^2 and grain yield - Season 2002

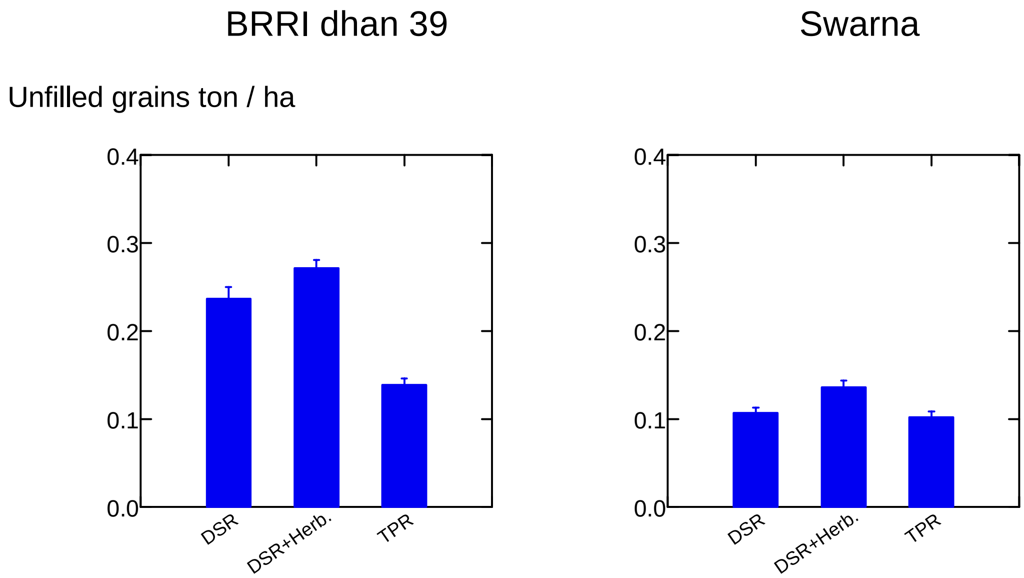


Figure 6 d) Unfilled grains - Season 2002

Weed management practices for direct seeded rice: Trials undertaken by BRRI/RLRRC on high and medium toposequence positions in direct seeded aman rice at Rajabari in 1998 and 1999 demonstrated that the use of the herbicide Ronstar has potential for controlling the initial weed burden which is associated with direct seeding. Results have been summarised in Mazid et al., (2001). An additional pre-plant ploughing may also benefit direct seeded rice. A high seed rate leads to the crop lodging, is associated with low yields and is not appropriate as a component of weed management. The trial was therefore re-designed for 2000 to look at favorable treatments in more detail. A split-plot design was used with the following treatments:

Main Plots:
1. Undertake one early additional cross ploughing in mid-May with country plough
2. No early ploughing

Sub-plots for Weed control treatments:
1. Hand weed at 21, 35 and 49 DAS
2. Ronstar (1.5 l ha^{-1} oxidaiazon) applied 4 DAS + hand weeding at 35 DAS
3. Sofit (1.5 l ha^{-1} pretilachlor + safener) applied 6 DAS + push weeder/hand weeding at 35 DAS
4. Ronstar + push weeder/hand weeding at 35 DAS
5. Push weeder/hand weeding at 21 DAS + hand weeding at 35 DAS
6. Hand weeding at 30 and 65 DAS (Approximate farmer practice in transplanted rice).

Table 16. Effect of pre-plant tillage and in-crop weed control treatments on crop stand, tiller number, yield of dry seeded rice and weed weight on upper and medium toposequence fields at Rajabari in *Aman* 2000.

	Stand 17 DAS m^2	Tillers 63 DAS m^2	**Weed wt** 21DAS g m^2	Yield kg ha^{-1}
Pre-plough	149	367	51	3905
Normal	111^{NS}	371^{NS}	62^{*}	3610^{*}
High land	110	422	29	3254
Medium land	149	317^{***}	85^{***}	4261^{***}
3 x Hand	124	376	56	3823
Ronstar +hand	115	390	46	3941
Sofit + weeder	110	348	52	3561
Ronstar + weeder	104	359	49	3559
Weeder + hand	125	386	67	3806
"Farmer"	199^{NS}	356^{NS}	68^{NS}	3825^{NS}

Significance levels (ns = not significant; * = P<0.05; *** = P<0.001) refer to data in each column.

Table 17. Significance levels (ANOVA) of effects of treatment on rice (BRRI dhan 39) grain and straw yield and panicle number at two toposequence positions in 2001.

	ANOVA significance levels (P)			
	High land		Medium land	
	Tillage	Weeding	Tillage	Weeding
Grain yield	**0.055**	**0.010**	0.657	**0.043**
Straw yield	0.828	**0.039**	0.474	0.076
Panicle number	0.837	0.884	0.466	0.171

Table 18: Effect of weed control practice on rice (BRRI dhan 39) grain yield at two toposequence positions in 2001.

	Grain yield t ha^{-1}	
Treatment	High land	Medium land
Hand weeding 21, 35, 45 DAS	2.75	3.09
Ronstar 1.5 l ha^{-1} + hand weed at 35 DAS	2.69	2.83
Sofit 1.5 l ha^{-1} + hand weed at 35 DAS	2.39	2.81
Ronstar 1.5 l ha^{-1} + weeder at 35 DAS	2.30	2.56
Hand weeding at 35 DAS + weeder	2.19	2.61
Hand weeding at 35 + 86 DAS	2.10	2.87
S.E.D (19 d.f.)	0.18	0.16

- Additional early ploughing before seeding resulted in significant yield increases in 2000 and on highland in 2001(Table 16 and 17). Pre-ploughing led to reduced weed biomass prior to first weeding at 21 DAS.
- Yields resulting from the use of Ronstar, followed by one hand weeding were as good as those achieved from three hand weedings undertaken by 45 DAS (Table 18). Sofit did not achieve as good weed control as Ronstar and yields were lower as a consequence following use of Sofit. Yields were also lower when following the herbicide or a delayed first weeding by use of a push weeder, probably because weeds emerging later with the crop row are not controlled.
- These trials demonstrate that integration of a herbicide with a follow-up hand weeding can result in yields similar to those following intensive hand weeding. Ronstar is currently the only herbicide registered in Bangladesh which is fully selective in direct seed rice. Sofit is not available.
- Farmers should now be made aware of the option of using direct seeding with a herbicide for weed control in the *aman*. However, rainfall timing and amount can be very variable during the early part of the monsoon and heavy rainfall immediately after applying Ronstar may lead to poor weed control. Farmers in the Barind have little scope for managing water on rain-fed fields. Further work should now be undertaken to validate the use of direct seeding with a herbicide on-farm at a range of toposequence positions at a number of locations to determine the likely cost:benefit of the system. This needs to take into account the yield of direct seeded compared to transplanted rice, labour costs for establishment and weeding and, the additional income generated by any increased opportunity to grow a *rabi* crop when rice can be harvested earlier following direct seeding.

<u>Seed priming as a component of direct seeding:</u> Seed of primed (soaked in water overnight) 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 in 2000 and 2001. Seedbed preparation was by cross ploughing. The "dry bed" was moist but aerobic soil while the "wet bed" was saturated soil. Data were collected on plant stand, tiller number, rice plant height, phenology, panicle number and yield.

Chickpea BARI Chola 2 was broadcast immediately after rice harvest and incorporated by cross ploughing with an animal drawn country plough. Chickpea was sown at 45 kg ha (dry seed). No weeding was needed in the chickpea crop. Data was recorded on emergence date, crop stand and yield.

Table 19. The effect of pre-planting seed priming on the growth and yield of direct seeded *T-aman* rice cv. BRRIdhan 39 (*Aman* 2000).

	Dry Bed		Wet bed	
	Primed	Un-Primed	Primed	Un-Primed
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

Table 20. The effect of pre-planting seed priming on the growth and yield of chickpea broadcast planted on rice stubble.

	Primed	**Um-primed**
Planting date	2nd November	
Emergence	4 DAS	6 DAS
Leaflets	6 DAS	8 DAS
Plants m^2 at 16 DAS	41	30^{*}
Plants m^2 at 35 DAS	31	26^{NS}
Plants m^2 at podding	21	18^{NS}
Grain kg ha^{-1}	2216	2030^{NS}

Note: Significance levels based on ANOVA - RCBD with 4 replicates

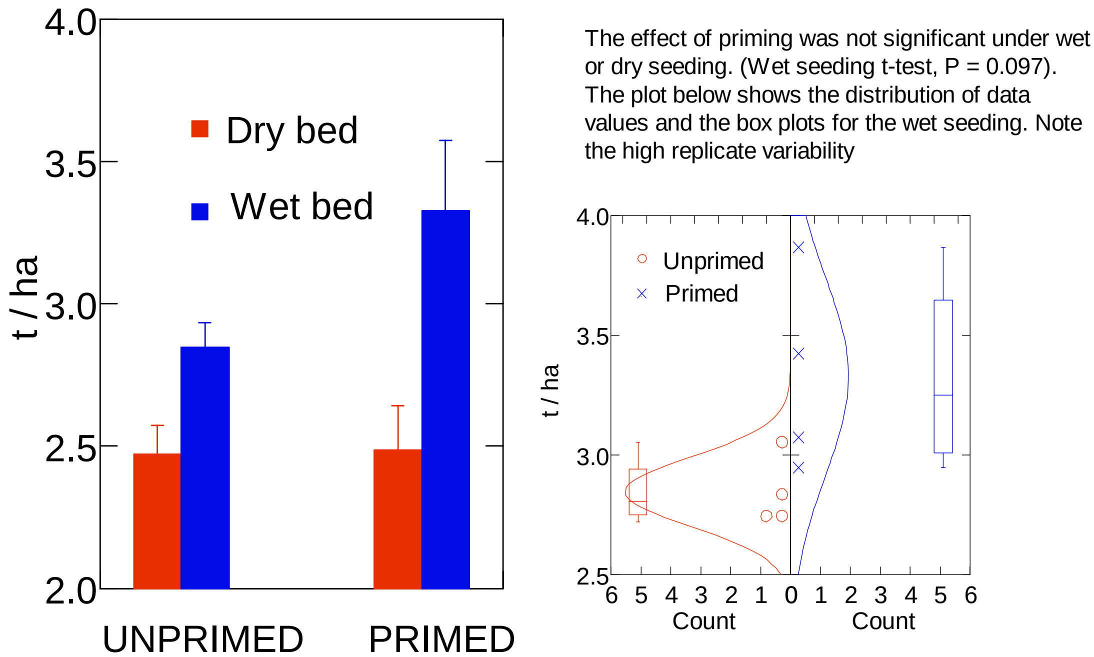


Figure 7. *Yields of rice variety BRRI dhan 39 grown from primed and unprimed seed at Rajabari,* aman *2001.*

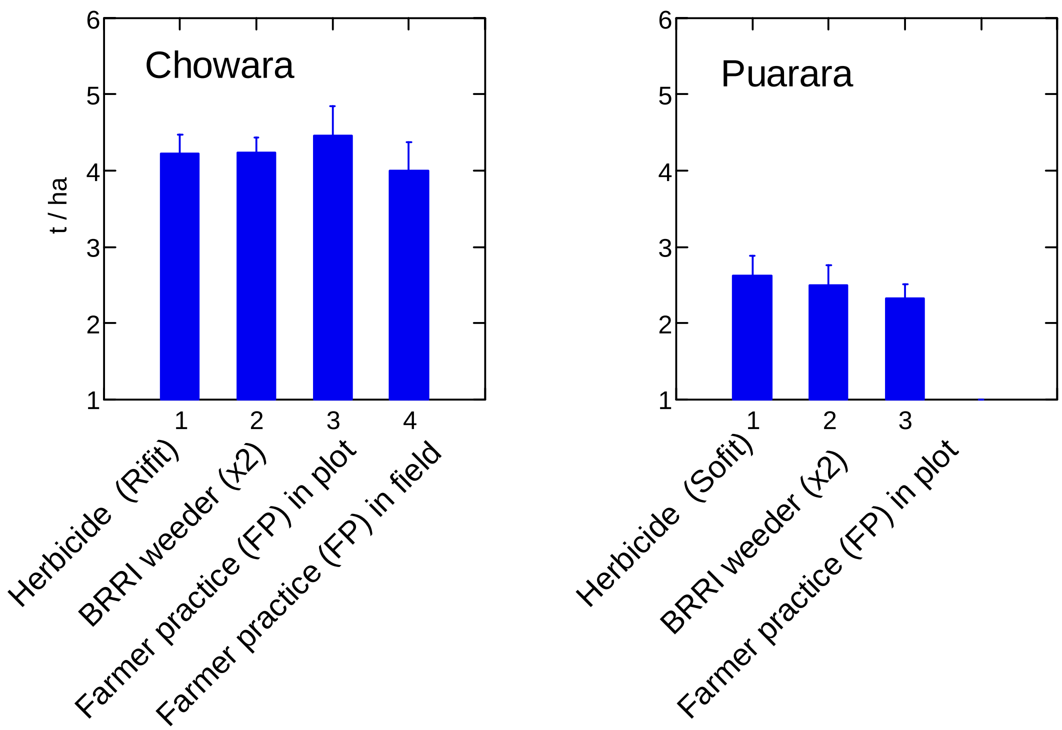
The results have shown:

- Priming resulted in improved rice stand establishment, tiller number at booting and panicle number on both dry and wet beds in 2000 (Table 19). Although higher grain yield were harvested from primed plots the difference was not statistically significant in either season (Table 19 and Figure 7).
- 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 priming did not advance crop maturity to allow earlier chickpea planting. On the evidence of this work it does not appear to be worthwhile promoting priming of direct seeded *aman* rice to farmers.
- Priming is being promoted to farmers in the Barind Tract of Bangladesh as a method for increasing the reliability of chickpea establishment and for increasing yield. There was no significant increase in chickpea yield following priming in 2000 (Table 20).

On-farm testing of weed management practices in Comilla:

On-farm trials were conducted at five sites in each of two villages in Comilla in *aman* 2001 and *boro* 2002 to evaluate weed control and rice crop performance following use of a herbicide, use of a push weeder designed by BRRI or farmer practice in transplanted rice. Two herbicides which are being promoted in comilla were used – Rifit (pretilachlor) in Chowara and Set Off (cinosulfuron) in Paruara). Tillage, crop establishment, water and nutrient management were undertaken by the farmers hosting the trials. Project staff provided assistance with herbicide application. Yields for *aman* season trials are shown in Figure 8.

Figure 8. Yields of rice following the use of various weed control practices in Chowara and Puarara villages Comilla – *aman* 2001. There were no significant difference between weed control practice.



- Use of a herbicide or weeder (with no additional hand weeding) resulted in similar levels of yield as farmer practice in T. *aman* 2001. Farmer practice was usually two hand weedings. The trial was also undertaken at five sites in each village during the 2002 *boro* season with similar results. In Chowara yields averaged 3.48 t ha^{-1} from farmer practice, 3.55 t ha^{-1} when the BRRI weeder was used and 3.60 t ha^{-1} following use of the herbicide Rifit. In Parura yields were 3.52, 3.68 and 3.79 t ha^{-1} for these treatments respectively, with cinoculfuron being used as the herbicide.
- Some indication of the cost advantage of using a herbicide was obtained from discussions with farmers in Comilla who hare started to use chemical weed control (see next section). Based on the dose of herbicide farmers are actually using and 1.5 labour days for follow-up hand weeding, the cost of weed control, excluding food for labour, is approximately

Bangladesh TK 800 per acre if Rifit is used. At a labour price of TK 70 per day this represents a saving of TK 880. Savings are even greater if the costs of food for labour and procurement costs are taken into account.

Weed competitiveness in rice: Studies funded by DFID IPM Strategy Area and CRF funds at WARDA in W. Africa and on-going work at IRRI have demonstrated that large differences exit in the competitiveness of rice cultivars with weeds. This project has supported field-work at BRRI HQ, Gazipur, to characterise the morphological traits that are thought to be associated with competitiveness of local and introduced lines. Selected lines have also been grown in replicated trials in the presence and absence of weeds. Significant differences in plant height at maximum tillering, tiller number and leaf area index have been reported among 11 local, three advanced breeding lines and four BRRIdan *aman* lines (Mazid et al. 2001).

Fifteen lines were planted in a split plot design in 2001 *aman* in which main plots were either maintained weed free or left weedy. The effect of weeding level (P = 0.015), cultivar (P <0.001) and the weeding by cultivar interaction (P <0.001) were all significant. Large differences were observed in the yield stability of cultivars between weeded and unweeded plots (Table 20). The recently released modern cultivar BRRI dhan39 appears to maintain yield under weed pressure in contrast to some other lines including IR 36 which has been shown elsewhere to be a poor competitor.

Table 20. Effect of weed management on cultivar yield, Gazipur *aman* 2001

Cultivar	Weeded	Unweeded
IR72	2.353	2.140
IR36	2.277	1.293
IR64	3.253	3.477
BG90- -2	2.480	1.620
BADSHAHBHOG	1.783	1.463
KATARIBHOG	2.833	3.083
TILOK KATCHARI	2.670	2.443
ASAMI KHELAPI	2.047	2.413
ANAPIA	3.407	3.267
BINNA	2.277	1.860
BRRI Dhan34	2.037	1.687
BRRI Dhan39	3.623	3.420
BR23	3.167	3.020
BRRI Dhan37	1.867	1.713
BR22	2.540	2.650
S.E.D. (56 d.f.)	0.099	

A set of 22 lines developed at WARDA, including *Oryza glaberrima* x *O. sativa* inter-specific hybrids were obtained by the project and grown for the first time at Gazipur in *aman* 2001. The inter-specific crosses are not adapted to conditions in the *aman* at this site. Only one line (WAB450-1-B-P-38-HB) yielded more than 1 t ha^{-1}. Among other materials however three lines, WITA 3, WITA 4 and WITA 12, yielded in excess of 5 t ha^{-1} in this non-replicated observation compared to 3.5 t produced by the local check BRRI dhan 39. Four of the most promising of the

WITA lines were included in a replicated trial in the 2002 *aman*. Rice line and weeding regime ($P<0.001$) and, line x weeding regime ($P = 0.02$) were significant (Table 20).

Table 21. Grain yield (kg ha^{-1}) of six rice lines when weeded or left unweeded, *aman* 2002, Gazipur.

Rice line	**Weeded**	**Unweeded**
WITA 3	2983	2331
WITA 4	2964	3022
WITA 8	2367	871
WITA 12	2826	2065
FARO 8	2142	2237
Kataribhog	2833	1966
S.E.D (21 d.f.)	324	
$LSD_{0.05}$	675	

WITA 3, WITA 4 and the cultivar FARO 8, identified as performing well in the presence of weeds in earlier work at Gazipur, produced similar yield when weeded or left weedy. In this particular season their performance compared favourably with that of BRRI dhan39, now recommended for the *aman* season by BRRI. Although not included in this trial it was transplanted at the same time on adjacent plots to produce 2810 kg ha^{-1}. The performance of the WITA lines over two seasons generated considerable interest among BRRI rice breeders who made selections to use in future work. The grain technology section at BRRI has examined the entries from West Africa and reports that the WITA lines are course grained rice of good quality. WITA 3, WITA 8 and WITA 12 were also planted in observation plots at Gazipur in *boro* 2002 wnen they produced between 6 and 6.8 t ha^{-1}. WITA 4 and WITA 12 have now been taken to on-farm trials for *aman* 2003 in the Sunamganj area of Great Sylet region in northeast Bangladesh. Because they are fairly tall it is thought that they should perform well in the area were fields tend to have fairly deep water during the *aman* season. These trials will be conducted by a BRRI managed cropping systems project funded by PETRRA.

Output 5: Findings disseminated through IRRI Weed Ecology Working Group and at end of the project via a workshop for NGOs and extension staff.

Project findings were disseminated within Bangladesh, at regional meetings in south and south east Asia and through poster presentations and publication in international conference proceedings.

<u>Dissemination in Bangladesh</u>: A joint Rainfed Lowland Rice Research Consortium/Weed project workshop was held at BRRI, HQ in Gazipur in March 2001 to discuss results from work undertaken during 2000 *aman* and plans for the remaining seasons of the project. Eleven presentations, based on work undertaken by the project, were presented and are included in the proceedings (Mazid *et al*., 2002). Two dissemination workshops were organised towards the end of the project in September 2002. Held in Comilla and Rajshahi these one-day meetings were aimed at lead farmers, DAE and NGO extension staff. The workshops also provided an opportunity to develop outlines, with stakeholders, for the activities of follow-on project R8234 “Promotion of cost-effective weed management practices for lowland rice in Bangladesh”. Each workshop was attended by 50 to 70 farmers, extensionists and researchers and was covered by journalists from a number of local and national newspapers. Participating extension staff came from regional, district, Upozilla and block (field) level. Extension leaflets, based on project

results were distributed to participants and subsequently to extension officers in the districts. For Comilla 2,500 of the two leaflets attached in appendix 2 were printed:

- "DhanKhete Agacha Daman" (Weed control in rice fields – concentrated in herbicides)
- Nibir Dhan Chashe Karjokari Bhabe Agacha Daman" (Effective weed control in intensive rice systems – provides information on integrated weed management).

For Rajshahi three fact-sheets were prepared and distributed at the workshop. These were all printed in Bengali:

- Herbicide use in rice
- The problem of weeds in rice
- Extending farm productivity in the Barind, rice and *rabi* cropping (covering the rice/*rabi* system and rice weed control).

A colour poster, showing the major weeds of rice in the Barind has also been prepared (Appendix 5). This will be printed in Bangladesh and distributed to extension department offices.

During the final year of the project farmer field days were also organised. In Comilla, farmers and extension staff were shown on-farm trials of weed control practices for *boro* rice and in Rajshahi a field day was held at the Rajabari key site prior to the chickpea harvest.

Regional meetings: The Weed Ecology Working Group (WEWG) is a small thematic group of collaborating NARES with the common strategic goal of developing integrated weed management practices for rice in south and south-east Asia. This project has supported the attendance of Dr J. Uddin at two work group meetings (IPM-net, Chang Mai, March 2000; IRRC, Bangkok 2002) and Dr M Mazid (Bangkok, 1999) in addition to attendance at the Brighton Crop Protection Conference 2001. The WEWG has recently received funding from the Swiss Development Corporation for the next three years and is in the process of extending its research agenda. (http://www.irri.org/irrc/weeds.htm) Dr J. Uddin is the representative member for Bangladesh and his participation will ensure that members from NARS in the region will continue to be made aware of research outputs from Bangladesh.

As RLRRC site co-ordinator Dr Mazid presented a summary of research findings, including project activities, from work in the Barind to a meeting of the consortium partners from key sites in India, Indonesia, Philippines and Thailand held in June 2001. A summary of findings from the long term experiment at Rajabari was included in a poster presented at the Philippines Weed Science society (Amarante *et al.,* 2002).

International meetings: Two posters presentations were made and papers published in the proceedings of the 2001 British Crop Protection Council Weeds Conference (Ahmed, *et al.*, 2001; Mazid *et al.*, 2001b). A paper has also been accepted for presentation at the BCPC International Congress in November 2003. Work from Comilla was highlighted in a poster paper prepared for the Asian Pacific Weed Conference, held in Manila in February 2003. These posters and papers are included on the CD attached).

CONTRIBUTION OF OUTPUTS TO DEVELOPMENTAL IMPACT

The Bangladesh economy is now launched on a growth path that will make it a middle-income economy by 2020. This structural change will have a profound impact on the rice sector of the rural economy. Among these impacts are the continued decline in the real price of rice and the growing competition for labour with the non-farm sector, which is now the fastest-growing source of employment in the rural economy.

This macro-economic perspective is essential for understanding the rationale for modifications to rice cropping practices, including improved weed management, and the forms that such improvement might take. Farmers confronted with a cost-price squeeze in rice production will either diversify out of rice or seek new ways to cut unit costs. In districts of intensive rice cultivation like Comilla, where rice is double or triple-cropped, the scope for savings in unit costs is limited since tillage and post-harvest operations are already mechanised. Weeding, however, remains highly labour-intensive and competition for labour has intensified. This explains the widespread interest in herbicides. Aided by aggressive marketing from chemical companies, conditions are now ripe for a massive expansion in herbicide use. This will reduce employment for agricultural labour but the indirect benefits will be transmitted largely to the poor through continued low rice prices. Also, it must be remembered that the direct beneficiaries will include resource-poor farmers and sharecroppers who also employ hired labour for weeding. Project R7471 has made considerable progress to:

- Characterise rice-cropping systems, focusing on the role of weeds as a constraint to yield and system productivity.
- Understand both agronomic and socio-economic dimensions of weeds as a yield constraint, and their interactions to provide a systems framework for the development of weed management practices.
- Understand the factors that determine variability in weed flora composition and persistence, to provide a basis for the integration of crop establishment and in-crop weed control practices which impact on the long term persistence of weeds.
- Evaluate the role of weed management practices in reducing yield loss due to weeds in order to improve labour and system productivity.

In the two *aman* and two *boro* seasons during which the project has been implemented the focus has necessarily been on generating new information. This has been achieved and will place collaborating institutions and subsequently extension organisations in a position to provide farmers with cost effective and labour saving weed management options for wider demonstration in the future.

More efficient weed management is likely to have a twofold impact on poverty. Rice producers, the majority of whom are resource-poor farm households, will benefit directly from reduced rice production costs, reduced yield losses from weeds, and the improved potential (in Rajshahi) for dryland cropping in the *rabi* season. These impacts will improve income immediately to individual households adopting improved weed management practices. Sharecroppers also stand to benefit from improved weed management. Studies undertaken by R7471 have identified that sharecropped plots, cultivated by some of the poorer households, are less likely to have access to mechanised tillage and were weeded less frequently and later, than owned plots. They were also less likely to grow modern varieties (MVs). Share crop farmers will benefit from higher *aman*, yields because, in a 50:50 share contract, they retain higher absolute amounts of paddy. On sharecropped plots, therefore, farmers might be willing to adopt innovations like herbicide use that boosted *aman* yields by reducing crop losses from weeds. Conversely, they might be less willing to adopt innovations like direct-seeding that, although reducing labor costs and allowing earlier sowing, offer greater risk of reduced *aman* yields. Rice consumers, the majority of whom are landless households, will benefit indirectly by the contribution that improved weed management can make to ensuring continued growth of rice production. In some areas of the Barind Tract, additional employment from irrigation has doubled real wages for agricultural labour in the past 20 years (Westergaard, 2000). Long term prospects for further decline in poverty in Bangladesh also depend critically on a continued fall in rice prices, since poorer households spend above half their income on rice. Because of its high capital costs, *boro* production is highly sensitive to changes in output prices. Consequently, this continued fall in rice prices would depend on maintaining price incentives for rice producers by improving efficiency through methods such as improved weed management.

The project goal agreed with CPP for this project was "Yields in rice-based systems in flood plain areas increased by environmentally benign pest control methods." The project has clearly demonstrated that improved weed control will need to be an essential component of pest management if average yields of lowland rainfed rice are to be increased. By building upon earlier work in Bangladesh and through a study of the effectiveness of weed management within existing systems, the project has contributed to an understanding of what the elements of cost-effective weed management strategies need to be, if these are to have an impact. As a result the knowledge gained by the project can be used as the basis for promoting improved weed management methods in the single rice *aman* crop and intensified multi-crop *aman-boro* and *aus-aman-boro* systems. Successful weed management results when farmers are able to integrate a set of crop management decisions which lead to the establishment of a vigorous, competitive crop in which timely in-crop weed control is achieved. Knowledge on the effects weeds on the crop, timeliness of operations, how to use individual control practices effectively and the long term impact of cropping practices on weed populations themselves is key to effective farmer decision making. The project has provided information on these issues in leaflets and fact sheets which are accessible to extension and NGO workers to use in farmer training. The project has identified that increasing use of herbicides in intensive rice systems in Bangladesh is inevitable. As herbicides are inexpensive, and reduce input costs over hand weeding, widespread adoption by resource poor households is also likely. With adequate training the modern low field dose products, which have favorable toxicology profiles, now on the market in Bangladesh can be used safely. Once again farmer access to knowledge is the key to ensuring that herbicides are used as a component of an integrated environmentally benign pest control programme in lowlands of Bangladesh. The working paper on herbicide adoption circulated to and discussed with the agrochemical companies that supply the Bangladesh market has started the process of raising awareness of the issues on which farmers need additional information.

The policy debate about how to increase farm productivity and livelihoods in the Barind has also been informed by findings from the project. This analysis suggests two situations in which the promotion of improved weed control to contribute to increased rice productivity in the area; in the existing T- *aman* and in rice established by direct seeding. R7471 has identified that late first weeding is a feature of T- *aman* in the Barind, partly due to a labour constraint, particularly on larger farms. Late weeding combined with a shortage of labour suggests a ready market for herbicides and as elsewhere any expansion of use will need to be accompanied by provision of information to farmers.

Analysis of the current situation and potential for change indicates that interventions to expand *rabi* cropping in the High Barind may distinguish two broad target groups. 1) Larger farms with lower cropping intensity and the potential to grow *rabi* crops under relatively favourable conditions; Interventions for this group should focus on raising the area planted. 2) Smaller farms with higher cropping intensity and limited potential to grow *rabi* crops under favourable conditions. Interventions for this group should focus on raising yields. In either scenario increasing the range of options available to farmers for weed control will be necessary if direct seeding, is to be widely adopted. Trials completed by R7471 have shown that one application of the pre-emergence herbicide oxadiazon, used in combination with a follow-up hand weeding allows the rice crop to establish and grow in weed free conditions early in the season and to produce yields comparable with transplanted rice. Widespread validation of direct seeding with herbicide use by farmers, is now needed as the next step in the promotion of this component of an improved, low labour demanding and productive *aman* rice/*rabi* system.

HOW THE OUTPUTS WILL BE MADE AVAILABLE TO INTENDED USERS?

Information generated by the project can assist in farmer weed management decision making provided it is packaged in suitable forms and becomes available through channels which farmers trust. As described above a number of leaflets and fact sheets have been produced and made available to extension officers in Comilla and Rajshahi. However the task is now to ensure maximum exposure of farmers to the available options and to provide them with information on the "best-bet" practices for the different cropping seasons depending on soil, land types and the extent of water control. This work will be undertaken through a new CPP project (R8234). This will scale-up the testing and promotion of outputs from project R747 in Bangladesh in intensive irrigated rice (Comilla District) and rain-fed rice-*rabi* systems (High Barind Tract) by working with farmer groups supported by Extension, NGOs, Bangladesh Rice Research Institute and the private sector. The objective will be to disseminate improved practices for sustainable, cost-effective integrated weed management, including herbicides and mechanical weeding. The project will collaborate with the private sector to develop 'best-practice' in information dissemination along the product supply chain to empower farmers to make informed decisions about herbicide use.

The new project will undertake training of trainers, promotion and other field activities. In Comilla it will facilitate and support activities funded by PETRRA and undertaken by the NGO SAFE in collaboration with Syngenta and BRRI. This project, "Improved Information Flows from Private-Sector Suppliers for Weed Management in rice" will be undertaking farmer field schools as part of an evaluation of information supply on herbicides and weed control from the private sector to farmers. The SAFE work will link the project directly to 100 resource-poor farmers in two upazilas, administrative units within Comilla district. Through BRRI, validation trials of weed management options will be implements in both *boro* and T-*aman* seasons on at least 60 sites. Collaboration with DAE will lead to demonstrations and farmer-field days on best-bet practices in five upozillas. Information leaflets developed to date will be field tested and modified as needed prior to wide dissemination. The project will work with the company Syngenta, also a partner in the SAFE project, to develop appropriate information resources on herbicide use as a component of integrated weed management. It is proposed that by the end of the project information leaflets will be distributed through the Syngenta village dealer network, which currently employs 10,000 retailers. The distributors of other herbicides will also be encouraged to become involved in supplying information to farmers along the supply chain.

In the rice-rabi system of the Barind Tract, the project will place on-farm validation plots at 24 farm sites across two districts. These will determine the situations under which switching from transplanting to direct seeding is cost:effective within the context of increasing the opportunity for *rabi* cropping. With DAE there will be a minimum of 100 block demonstrations of rice/rabi cropping pattern with improved weed control. These will be placed in villages across three districts. This work will be undertaken in collaboration with the NGO PROVA that will also receive funding from the DFID Plant Science Research Programme. This will allow system demonstrations to be undertaken of best bet practices for *aman* rice (funded by CPP) and for *rabi* crops including chickpea (funded by PSRP) at the same sites.

Modelling of the impact of the promotion of improved rice establishment and weed management will be undertaken to consider the future policy implications for the design of wider scale promotion of weed control recommendations. Given the heterogeneity of the farm sector, it's range of land-types, large differences in farm size, and high levels of sharecropping, a farm modelling approach will help understand the interactions between short-duration MVs, direct-seeding, herbicides, and *rabi* cropping in the Barind or weed control practice and water management in Comilla. Research will focus on creating simple but robust models for “resource-poor” and “large” farms to explore the economic returns from new technology and the impact on demand for landless labour. The results will provide BRRI with a tool to provide a greater understanding of the farming system, and will allow a more accurate assessment of uptake by farmers for policy makers. It is expected that the results from farm modelling will be useful in tailoring recommendations for target groups and for identifying potential constraints on uptake, particularly among resource-poor farmers or sharecroppers.

PUBLICATIONS SUMMARISING RESULTS FROM R7471

Working Papers – See CD attached

M.A. Jabber, G.J.U. Ahmed, M.A. Mazid, A.W. Orr, E.J.Z. Robinson and C.R. Riches (2002) Weed management in floodplain rice in Comilla and Rajshahi Districts, Bangladesh: characterisation studies 2000-01. Working paper, BRRI, Gazipur; NRI, Chatham, UK, pp 44.

Orr, A.W. and Jabber, M.A. (2002a) Farmers’ weed management for T. *aman*, Bangladesh. Working paper, BRRI, Gazipur; NRI, Chatham, UK, pp 27

Orr, A.W. and Jabber, M.A. (2002b) Expanding *rabi* cropping in the high Barind Tract, Bangladesh: a socio-economic perspective. Working paper, BRRI, Gazipur; NRI, Chatham, UK, pp 26.

Orr, A.W. and Jabber, M.A. (2002c) Interactions between weed and water management in *boro* rice, Comilla district, Bangladesh. Working paper, BRRI, Gazipur; NRI, Chatham, UK, pp 27

Riches, C.R., Ahmed, G.J.U., Badsha, M.A. and Bhuiyan, M.K.A. (2002) Herbicide Adoption in Comilla District, Bangladesh. . Working paper, BRRI, Gazipur; NRI, Chatham, UK, pp 27

Conference Papers and Posters – See CD attached

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Final version of logframe for project R7471:

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Important Assumptions
Goal			
Yields in rice-based systems in flood plain areas increased by environmentally benign pest control methods.	To be completed by Programme Manager	To be completed by Programme Manager	To be completed by Programme Manager
Purpose			
Improved and cost effective methods for the control of weeds in floodplain rice production systems developed and promoted.	To be completed by Programme Manager	To be completed by Programme Manager	To be completed by Programme Manager
Outputs			
1. Crop and weed management practices and farmers' perceptions of weeds and control measures described.	Stakeholder workshop in Q3 of 99. RRA complete by 10/00. Farmer evaluation of on-farm trials by 06/02.	Project Q reports; presentation at IRRI RLRRC meeting; Conference & journal papers.	Outputs 1-5. - BRRI allocate adequate scientist and social scientist time to project activities
2. Weed populations within different ecologies and the influence of crop and weed management practices described.	Monitoring completed in boro and T-Aman for three cycles by 6/02. Yield gap studies by 10/01	Project Q reports, conference and journal papers.	- Adverse weather conditions do not prevent timely achievement of outputs
3. Persistence, dormancy and quantity of weeds seeds in the seed bank determined.	Detailed studies completed at Gazipur from Q4 99/00 until 06/02.	Project Q reports, conference and journal papers, presentation at IRRI Weed Ecology working Group & RLRRC.	
4. Integrated weed management strategies to reduce the build-up of weed populations developed.	On-station trials complete at two locations and on-farm at selected locations by 06/02.	Project Q reports, conference and journal papers, leaflets distributed to NGOs and extension staff	
5. Workshop to present project findings.	Workshop held by 08/02.	Workshop proceedings	
Activities	**Inputs**	**Means of Verification**	**Important Assumptions**
1.1 Stakeholder workshop to establish detailed work programme	Total budget: £259,410		
1.2 RRA and focus groups in target communities			

2.1 Workshop to agree study sites.			
2.2. Monitoring of weed composition on-farms under different management.			
2.3 Yield gap studies on-farm.			
3.1 On-station studies of weed seed banks and periodicity of germination of key species.			
4.1 On-station trials to evaluate impact of crop establishment, fallow management and rotations on weed populations.			
4.2 Weed management options evaluated in on-farm trials			
5.1 BRRI staff participate in IRRI Weed Ecology meetings.			
5.2 Workshop to disseminate findings in Bangladesh.			
5.3 Prepare extension materials			

Appendix 1

End of project Workshop on “Cost Effective Weed Management in Rice in rainfed Rice-Chickpea cropping system”. Rajshahi. 5 September, 2002.

Participants:
BRRI (HQ): Dr. A. R. Gomosta, Director (Research) and CASR,
Dr. M. A. Salam , Chief Plant Breeder,
Dr. B. A. A. Mostafi, Chief Agriculture Economist,
Dr. M. A. Jabbar, Principal Agriculture Economist,
Dr. Sayedul Islam, Principal Agriculture Engineer & Head incharge, FMPHT Division.
Senior Adaptive Research Specialist, Adaptive Research Division
BRRI Regional Stations:
Dr. M. A. Mazid, Principal Agronomist, BRRI1 Rangpur,
Mr.M.A Kader, Plant Breeder, BRRI Rangpur
Dr. M. A. Nahar, Chief Plant Pathologist, BRRI Rajshahi
Mr. Mir Moniruzzaman, Principal Farm Management Specialist, BRRI Rajshahi
Dr. Ansar Ali, Senior Plant Pathologist, BRRI Rajshahi
Mr. Biswajit Karmakar (Adaptive Research Specialist), BRRI Rajshahi.

NRI : Dr. Charlie Riches, Weed Scientist

IRRI : Dr. Martin Mortimer, Weed Ecologist

PROVA/CONSULTANT: Dr. C. Johnsen

DAE: Mr. Fazlul Haque, Additional Agriculture, Rajshahi Region, DAE
Mr. Rezaul Karim, Deputy Director, DAE, Rajshahi
Mr. Robin Mojumder, Deputy Director, DAE, Chapai Nawabganj,
Upozilla Agriculture Officer, Godagari , Rajshahi
Upozilla Agriculture, Tanore, Rajshahi
Upozilla Agriculture Officer,Nachole, Nawabganj

Block Supervisors of Rajabari (Godagari), Talupara(Tanore)& Lokkhipura(Nachole)

Other Institutions:
Head, Wheat Research Center, BARI, Shyampur, Rajshahi
Head, On Farm Research Division, BARI, Rajshahi
Head, Soil Resource Development Institute, Rajshahi
Regional Head, Agriculture Information Service, Rajshahi
Dr. M. Shajahan, Consultant, SDC, Rajshahi

NGO:
PROVA: Mr. Abu Musa, Executive Agriculture Advisor, PROVA, Rajshahi and
Field Worker of Godagari,Tanore, Nachole and Chapai Nawabganj Sadar

CARE: Representative of PM (LIVE project), Rajshahi, Field Worker
BRAC: Representative of RM, Rajshahi

Farmers:
Participating farmers from Rajabari, Godagari, Rajsjaji (6), Tanore, Rajshahi (6) & Nachole, Chapai Nawabgani (6)

Non participating farmers from 4 upozillas

Media people (5) from Daily Ittefaq, Daily Sangram, Daily Observer, Independent and a local newspaper SONALI SANGBAD

Programme

Time (hr)	Activity	Name of the concerned
0830-0900	Registration	Mr. Biswajit Karmaker, SO, BRRI Rajshahi Mr.M. A. Kader, SO, BRRI Rangpur
Inaugural Session		
0900-0915	Guests take their seat	
0915-0920	Talawat-e-Quaran	Mr. Abu Taher , Imam, BRRI Rajshahi
0920-0930	Welcome address	Dr. M.A. Nahar, CSO & Head BRRI Rajshahi
0930-1000	Short speak on the Objectives of the workshop & future direction	Dr. M. A. Mazid, Site Coordinator, CURE & PSO & Head, BRRI Rangpur Dr. M. Mortimer, IRRI Weed Ecologist Dr. C. Riches, NRI Weed Scientist
1000-1020	Speech by the special guest	Mr. Fazlul Haque, Additional Director, DAE, Rajshahi
1020-1030	Speech by the chief guest	Dr. A. R. Gomosta, Director (Research),BRRI
1030-1035	Vote of thanks	Dr. Ansar Ali, SSO, BRRI Rajshahi
Technical Session		
1100-1145	Direct Seeded Rice (DSR), early maturing aman variety, weed control methods and yield gaps due to weeds in High barind soil	Dr. M. A. Mazid, Site Coordinator, CURE & PSO & Head, BRRI Rangpur
1145-1210	Weed Control Methods and livelihood improvement in Rainfed Rice-Chickpea cropping system	Dr. M. A. Mazid, Site Coordinator, CURE & PSO & Head, BRRI Rangpur
1210-1235	Weeds identification in drought prone Barind soil	Mr. Biswajit Karmaker, SO, BRRI Rajshahi
1235-1300	Discussion	All participants
1300-1400	Prayer & lunch	
1400-1430	Chickpea Cultivation Methods	Mr. Abu Musa, PROVA, Rajshahi
1430-1500	Factsheets-Herbicides use in rice	Dr. M. A. Mazid, Site Coordinator, CURE & PSO & Head, BRRI Rangpur
1500-1550	Discussion & future planning	All participants
1550-1630	Remarks / Comments from special issues on the use of herbicide	Dr.M.Mortimer, IRRI Weed Ecologist Dr. C. Riches, NRI Weed Scientists
1630-1645	Closing speech	Dr. A. R. Gomosta, Director(Research), BRRI
1645-1700	Tea and departure	