Summary The research and development challenge in the drought-prone rain-fed agriculture of the High Barind Tract of NW Bangladesh is to simultaneously improve the reliability and yield of aman (monsoon) rice (*Oryza sativa* L.), whilst improving total system productivity by increasing the area grown with post-rice (*rabi*) dryland crops. Research demonstrated that both dry and wet direct seeding of rice (DSR) resulted in yields (seasonally dependent and ranging from 2–4 t ha⁻¹) similar to, or higher than, those by conventional transplanting (TPR) and advanced rice harvest by 7 to 10 days. Earlier harvest had the potential to reduce the risk of terminal drought in rice at grain filling and increased the opportunity for establishing a high value *rabi* crop such as chickpea (*Cicer arietinum* L.) on residual moisture. Whilst DSR reduced the labour requirement at crop establishment, weed management by herbicide (oxadiazon) use was essential to protect yield from weed competition and further reduced rice production costs. Field scale evaluation of direct seeded rice systems by farmers validated research findings and emphasised the knowledge intensive nature of the technologies. As the Barind farming system is complex, DSR is not seen as a simple replacement of TPR but as an option that allows timely rice establishment with variable monsoon rainfall. Dissemination of these technologies will require local partnerships to build a reliable supply chain to deliver knowledge and inputs to farmers.

Keywords Direct-seeding, rice, chickpea, oxadiazon, diversification.

INTRODUCTION

The pre-dominant cropping pattern of the High Barind Tract of NW Bangladesh is a single crop of transplanted rice (TPR) grown during the monsoon *aman* season from June to October, when 80% of the 1200 to 1400 mm annual rainfall occurs, followed by fallow during the dry season. This area includes 100,000 ha of pre-dominantly rainfed land, accounting for some 12% of the drought prone rainfed lowland rice in Bangladesh (Mazid *et al*. 2001). Limited irrigation potential restricts cultivation intensity in the High Barind to below 175%. Approximately 20,000 ha is sown to a range of dryland crops planted on residual soil moisture after rice harvest in the *rabi* season, including chickpea, linseed (*Linum usitatissimum* L.) and mustard (*Sinapis alba* L.), or wheat (*Triticum aestivum* L.) where sufficient irrigation from farm ponds is available.

Late onset of the monsoon can delay rice transplanting as a minimum of 400 mm cumulative rainfall is needed to complete land preparation for transplanted rice (Saleh *et al*. 2000). In contrast, dry seeded rice can be sown after land preparation with only 150 mm cumulative rainfall (Saleh *et al*. 2000). Wet seeded (pre-germinated) rice sown by drum seeder on to puddled land removes the nursery bed requirement of TPR and can advance crop establishment by up to one month. Swarna, the most widely grown cultivar in the area, matures after 140 to 145 days and when transplanted may not be harvested until early to mid-November. In many years soil is drying rapidly at this time, reducing the likelihood of successfully establishing a high value chickpea crop. Advancing crop establishment by use of short duration varieties or by direct seeding reduces the risk of terminal drought, and allows earlier planting to ensure more reliable establishment of a post-rice crop (Mazid *et al*. 2001). Weeds however are a major constraint to adoption of DSR as the inherent advantage of weed suppression through puddling and transplanting rice into standing water is lost. The increased weed pressure after emergence of DSR may however be overcome by the timely application of a pre-emergence herbicide after seeding and follow-up hand weeding (Mazid *et al*. 2003).

MATERIALS AND METHODS

Long-term systems trial The productivity of two rice cultivars when direct seeded or transplanted was evaluated in the Barind (Rajabari district) in a long term-trial established in 2001. The modern cultivar, BRRI dhan 39 (maturity 120 to 125 days), was compared with the widely grown Swarna (maturity 150 to 155 days). The experiment was conducted as a split-split plot design with three main plots as crop...
establishment and associated weed management, four subplots as nutrient management, and two sub-subplots as cultivars. Establishment treatments were (1) transplanted rice (TPR), soil puddled prior to transplanting and plots hand-weeded twice at 30 and 45 days after transplanting (DAT); (2) direct-seeded rice (DSR), soil ploughed prior to dry seeding (2001 and 2004) or ploughed and puddled before sowing pre-germinated seed (2002 and 2003) in rows by hand, with hand weeding at 21, 33, and 45 days after sowing (DAS); (3) direct-seeded rice with chemical weed control (DSRH), as with DSR but with oxadiazon (375 g a.i. ha\(^{-1}\)) applied 2–4 days after seeding, with one hand weeding at 33 DAS. Nutrient regimes (kg ha\(^{-1}\)) were (1) single superphosphate and KCl 40 P + 40 K; (2) compound 60 N + 40 P + 40 K; (3) farmyard manure (FYM) + inorganic fertiliser totalling 60 N + 50 P + 50 K; and (4) diammonium phosphate (DAP) (18% N) + controlled-release urea (CR-N 45% N) totalling 43 N + 40 P + 40 K. Chickpea (cv. Barisola 2) was broadcast sown onto residual soil moisture after harvest of direct seeded rice and covered with soil by cross ploughing with an ox-drawn country plough. Total weed biomass was recorded in two unweeded quadrats per plot at harvest.

Field-scale evaluations Evaluation of direct seeding on a field-scale was undertaken with collaborating farmers during aman in 2004 and 2005. In 2004 dry seeding was contrasted with transplanting for cultivar Swarna (duration 140 to 145 days) on 13 farms. Dry seeded rice was sown into shallow furrows made by a manually drawn set of tines (lithao). Oxadiazon (375 g a.i. ha\(^{-1}\)) was applied 2–4 days after seeding (DAS) with a single follow-up hand weeding (at 30 to 40 DAS) when necessary. Comparative evaluation of dry (broadcast) seeding (13 farms) or wet (drum) seeding (13 farms) with transplanting on to puddled soil was made in 666 m\(^2\) plots. In direct seeded plots, weed control was by pre-emergence herbicide and hand weeding, oxadiazon being used in both instances. Weed control in transplanted rice involved pre-emergence application of pretilachlor (450 g a.i. ha\(^{-1}\), three days after planting) followed by hand weeding. Direct seeded plots were compared with transplanted rice established from seedlings raised in seedbeds sown on the same day, as fields were direct seeded.

In 2005 comparisons were made of dry seeding (lithao, 43 farms), drum seeding (11 farms) and transplanting (45 farms). Previous work had demonstrated that direct seeding can be undertaken on land classified as either ‘highland’ or ‘medium land’ fields on the terraced toposequence of the area.

RESULTS System trial Rainfall in May and early June was sufficient in 2001 and 2004 for sowing dry-seeded rice into moist soil during June (Table 1). In 2002 and 2003, an abrupt onset of the monsoon resulted in flooded fields so pre-germinated seed was sown on saturated soil in DSR plots after water levels fell. Drought during July and August 2003 delayed transplanting until late September, 92 days after DSR. Yields of DSR and DSRH exceeded TPR (Figure 1) in both cultivars except for 2002 (cv. BR39) and 2001 (cv. Swarna) when cropping system did not significantly influence yield. Yields of transplanted rice in 2003 were severely depressed by drought from early July to mid-August that led to late transplanting. Swarna exhibited a 1 t ha\(^{-1}\) higher yield than BR39. Over four years mean yields were highest from direct seeded rice (P <0.001), TPR producing 1.81 t ha\(^{-1}\) compared to 2.63 for DSR and 2.94 t ha\(^{-1}\) for DSRH (S.E.D. 0.13). The higher yields under direct seeding were accompanied by earlier maturity and harvesting dates (3 to 10 days) especially with BR39. On average the longer duration cultivar Swarna outperformed BR39 (P <0.001). Differential responses to crop establishment were observed for a number of important weed species. Densities of the perennial and annual grasses, *Cynodon dactylon* (L.) Pers. and *Echinochloa crus-galli* (L.) P.Beauv., and the annual sedge *Fimbristylis miliacea* Vahl. all increased in TPR while the broadleaf *Ludwigia hyssopifolia* (G.Don) Exell and the sedge *Cyperus difformis* L. increased in TPR. Populations of *Monochoria vaginalis* (Burm.f.) K.Presl. ex Kunth declined in both cases.

Yields of chickpea grown after DSR declined from 2001 (Table 1) due to increasing severity of *Fusarium* wilt. However over the period of the trial, yields were higher (P = 0.030) for crops planted after the earlier maturing rice cultivar BR 39 compared to those planted following Swarna.

<table>
<thead>
<tr>
<th>Season</th>
<th>Previous rice cultivar</th>
<th>BR39</th>
<th>Swarna</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001–2</td>
<td>1.01 ± 0.06</td>
<td>0.91 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>2002–3</td>
<td>0.76 ± 0.05</td>
<td>0.49 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>2003–4</td>
<td>0.38 ± 0.04</td>
<td>0.16 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>2004–5</td>
<td>0.31 ± 0.06</td>
<td>0.35 ± 0.06</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Effect of previous rice cultivar on grain yield (t ha\(^{-1}\) ± SEM) of chickpea sown after harvest of direct-seeded rice.
Field-scale evaluations In 2004 under farmer management, dry seeded crops of Swarna, sown into furrows made by lithao, out yielded adjacent transplanted crops, yields being 6.09 ± 0.24 and 5.71 ± 0.14 t ha⁻¹, respectively. Averaged over farmer chosen cultivars median planting dates for dry broadcast and wet drum seeded rice were 25 and 20 days earlier respectively than transplanted rice. These resulted in median harvest dates of 15th November for broadcast plots, 11th November for drum seeding and 20th November for transplanting with harvest continuing in transplanted fields for a week longer than direct seeded plots (Table 2).

The mean difference between transplanted and direct-seeded (dry and wet seeding pooled) rice yields was 0.04 ± 0.12 t ha⁻¹. There was also no significant effect of field location on the toposquence (P = 0.623) with high land fields producing 5.35 ± 0.14 and medium land fields 5.41 ± 0.08 t ha⁻¹.

In 2005 dry direct seeding, wet seeding with the drum seeder or transplanting all produced similar mean yields (P = 0.52) in field-scale evaluations.

DISCUSSION
The single rice crop, land pressure and a high proportion of share-cropping and other tenancy arrangements in the High Barind Tract, place a premium on optimising rice yield for household food security (Mazid et al. 2003). The results from this study indicate that rice yields are maintained or even increased.
compared to transplanting when the crop is either dry or wet seeded. The labour input needed to establish dry seeded rice using a lithao averaged 79 person hours ha$^{-1}$ compared to farmer estimates of 240 hours ha$^{-1}$ for nursery seedling management and transplanting. Three people were needed in a field when using the lithao (two to pull and one to steer), but farmers did not find this too arduous. Even larger labour savings were associated with drum seeding, as one person can use the implement. On-farm observations indicated a mean of 3.8 hours for establishing 1 ha of rice.

Herbicide use reduced weed control time in dry seeded crops to a mean of 84 hours ha$^{-1}$ compared to 590 hours ha$^{-1}$ in conventionally managed transplanted rice for which at least two hand weedings were needed. The trials demonstrated the importance when using herbicides in DSR of preventing the survival of herbicide tolerant species including annual and perennial grasses (e.g. Echinochloa crus-galli, Cynodon dactylon) and sedges by undertaking a follow-up hand weeding.

Direct seeding advanced the harvest date of Swarna and earlier maturing rice cultivars by as much as 7 to 10 days in the on-farm trials. To avoid terminal drought in rice and to allow post-rice crops to be sown while seedbeds are still moist an earlier harvest may be significant particularly when the monsoon ends abruptly in October. Farmers with the least land under cultivation (0.6 ha for the lowest quartile of households) on average plant 43% to post-rice crops, often on least favourable land where moisture is limiting (Mazid et al. 2003). Our trials suggest that this group can maximise rice yield and potentially improve timeliness of planting of a high value chickpea crop by direct seeding rice. On larger farms (>2.5 ha for upper quartile) a lower proportion of land after rice, is planted to rabi crops focusing on more favourable soils. Adoption of DSR by this group could result in an increase in the area planted to chickpea.

The advantages of particular strategies depend on rainfall probabilities. TPR in the High Barind Tract is delayed every other year by two weeks and every 10 years by one month (Saleh et al. 2000). Hence, dry-seeded DSR is an attractive planned strategy in ‘normal’ years. However, ‘excessive’ pre-monsoon rain occurs once every three years (Brammer 1997) favouring drum seeding or TPR. Similarly, a two week period without rain during the grain filling stage occurs once every two years (Saleh et al. 2000). DSR is therefore an attractive strategy in normal years to avoid late-season drought. Diversifying choices for farmers will require the development of decision-support systems that will allow extension workers to communicate this information effectively.

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