Expl Agric. (1999), volume 35, pp. 127–140
Printed in Great Britain

DETERMINANTS OF IMPROVING PRODUCTIVITY OF DRY-SEEDED RICE IN RAINFED LOWLANDS

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(*Accepted 17 June 1998*)

SUMMARY

Land and crop management practices were studied to determine yield stability and feasible measures to improve productivity of dry-seeded rice. Variability of yields among farms that had grown dry-seeded rice on the entire farm every season during the period 1991–95 was lower than among farms that had consistently grown transplanted rice during the same period. Weed control is a major challenge for dry-seeded rice and almost all farmers used herbicides to control weeds. Farmers who grew a non-rice crop before the rice season had better weed control than those who did not. Ploughing intensity and the type of implement used for land preparation were not significant factors for weed control. Field bund management was one determinant of productivity differences among farmers. The use of cross-bunds or periphery- and cross-bunds improved the efficiency of rainwater conservation and input use, and increased yields. Fields with higher levelling precision had lower water stress and produced better yields. On average, a farmer lost 0.93 t ha^{-1} yield due to land-levelling deficiency. The division of large and medium farms into a number of smaller plots improved levelling precision and water control, resulting in higher yields.

INTRODUCTION

Rice yields in the rainfed environments in the Philippines have remained low, even with the widespread adoption of modern varieties (De Datta *et al.*, 1988). Transplanted rice established on puddled soil facilitates soil nutrient availability, weed control and water retention (Sanchez and Bradfield, 1970; Taylor, 1972; De Datta and Kerim, 1973), but crop establishment requires large amounts of water and is labour-intensive. As both water and labour for rice culture are becoming scarcer, alternatives to the transplanted rice system are needed.

Studies conducted recently in a moderately drought-prone rainfed lowland area in Urbiztondo Municipality, Pangasinan Province, Philippines, have shown that dry-seeded rice (DSR) uses rainfall more efficiently, suffers less drought risk (IRRI, 1993) and is more profitable (IRRI, 1992) than transplanted rice (TPR). Seeds are sown directly on dry-ploughed land, eliminating the need for separate seedling culture, puddling of the soil, pulling from the seedbed and replanting of seedlings. The seeds germinate when the soil is soaked by pre-monsoon light

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rainfall. In addition to lower labour requirements for crop establishment, DSR also provides greater opportunities for non-rice crops such as mungbean to be grown in the wet season after the rice has been harvested. Mungbean (*Vigna radiata*) grown on DSR farms produced higher yields and income than when grown on TPR farms (IRRI, 1995) due to the greater amount of residual soil water in DSR farms.

Department of Agriculture statistics show that more and more farmers not only in Urbiztondo Municipality but also in nearby municipalities are adopting the DSR system, and consequently the TPR area has been declining (Fig. 1). During the past three to four years, there has also been a steady rise in the area grown to maize (*Zea mays*) prior to rice culture.

Almost all rice farms grow modern varieties in Urbiztondo, as in most other rainfed areas of the Philippines. As dry seeding in rainfed lowlands with modern varieties is a new technology, little is known about its performance characteristics. Although average productivity of DSR in the study area was low, some farmers consistently achieved much higher yields and income than others. A better understanding of how current technologies perform under field conditions is essential in order to identify where new, productivity-enhancing technologies are needed.

To complement earlier research findings on the advantages of the DSR system in rainfed lowlands, a study of the relationships between tillage practices, land-levelling quality, weeds and water status and DSR performance was conducted in 1994–95. The study aimed to determine feasible measures to improve productivity of DSR. This paper presents analyses of yield variability and stability of the DSR system, and the determinants of improving productivity of DSR in rainfed lowlands.

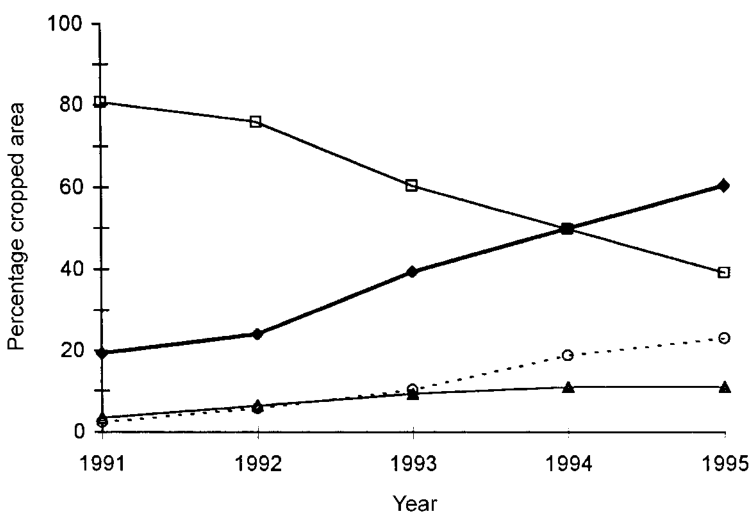

Fig. 1. Proportions of total rice under dry-seeded rice (—◆—) and transplanted rice (—□—) systems, and areas of pre- (– –○– –) and post- (—▲—) rice crops during 1991–95 (total rice area = 3026 ha) in Urbiztondo, Pangasinan, Philippines.

MATERIALS AND METHODS

Data used in this analysis were drawn from three sources: (a) data generated in a study of 26 farmers' crop production practices for three crop years (1991–93) in four adjacent villages of Urbiztondo Municipality, (b) a similar data set for 1994 and 1995 from selected subsamples of farmers who had grown either DSR or TPR on their entire farm every season during 1991–93, and (c) a complementary study conducted in the same area during 1994–95 on 50 farms (including data set (b) above) to identify the effects of different land and crop management practices on rice yield.

The dominant soil textures in the study area are silty clay and silty clay loam. The average farm is 0.5 ha in size and has a long narrow rectangular shape. There are about two paddies (plots) per farm. Rainwater conservation facilities on farms are generally poor. Although the long-term total annual rainfall in Urbiztondo is about 1500 mm, the rainfall during the rice season (June–October) is highly variable and the rice crop generally suffers from water stress.

Since the farms in the study area are laid out in strips along the main road, sample farms were selected systematically to include every other farm, starting with the second strip/farm from the main road. Farm level surveys were conducted to gather data from 11 farms using the DSR system and 15 using the TPR system during 1991–93. Information on input use and yield and other agro-economic data were collected by interviewing the sample farmers two or three times each season.

Standing water levels and perched water tables in the field were measured inside perforated PVC tubes, each 1.5 m in length and 25 mm in diameter, installed on each sample farm. Each tube was installed with 50 cm of its length above and 100 cm below the ground surface. Water levels inside the tubes and the water status of the fields were recorded every other day. Water stress in the rice crop was estimated by counting the number of days during which the perched water table was 30 cm below the ground surface. The total seasonal water deficit index (WDI, the sum of the product of the daily scaled water table depth below the ground surface and pan evaporation for the growing season) was calculated from the field water level data (Small *et al*., 1981) and used to analyse the effect of water stress on the crop. Crop cuts were taken from each sample farm to estimate grain yield and these yield data were compared with those obtained from the farm surveys. Two standard plastic rain gauges and a US Class A evaporation pan installed in the study area were used to measure daily rainfall and evaporation respectively.

During the 1994–95 wet seasons, 50 sample farms randomly selected from six villages were studied in order to document farmers' land and crop management practices, including tillage practices, land-levelling precision, weed problems, control measures and bund management status. The farm level water status and input–output information were also collected.

RESULTS AND DISCUSSION

Yield variability of DSR and TPR

About one-third of the sample farmers who practised the DSR system during 1991–93 obtained relatively high grain yields, between 3.60 and 7.03 t ha^{-1}. A similar proportion of TPR farms during the same period obtained mean yields between 3.50 and 5.90 t ha^{-1}. The 1991–93 mean yields of DSR and TPR farms were grouped into two categories: high (H, $\geqslant$3.50 t ha^{-1}) and low (L, <3.50 t ha^{-1}). The two groups were analysed for their productivity parameters.

The average DSR-H farm produced statistically the same yield (4.79 t ha^{-1}) as the average TPR-H farm (4.10 t ha^{-1}), but the DSR farm had a significantly higher return (Table 1). Labour expenses to establish the crop were significantly lower for DSR than TPR. The mean yields and generated returns from DSR-L farms were statistically the same as those from TPR-L farms. The data clearly indicate that there is significant potential for improving the yields of both DSR-L and TPR-L farms through appropriate management measures.

Yield variations during 1991–93 were less for the high than the low yield groups in both DSR and TPR farms (CV of yields of DSR-H = 23%, TPR-H = 14%, DSR-L = 38%, TPR-L = 32%). When the 1994–95 data set was used, the CV of the yields of DSR-H and DSR-L farms was much lower, 19% and 16% respectively. One possible reason for this was that most of the sample farmers in the data set had had more than five years of experience in growing DSR and had learnt how to establish and manage the crop better over that time. Variations in DSR yields during this period were mostly due to fluctuations in timing and in the amount of early-season rainfall, which affected crop establishment.

Table 1. Comparative costs and returns for dry-seeded (DSR) and transplanted (TPR) rice in high- and low-yielding farms in Urbiztondo, Pangasinan, Philippines in the 1991–93 wet seasons.

	DSR				TPR			
Item	High	Low	Average	S.e.d.	High	Low	Average	S.e.d.
Mean yield (t ha^{-1})	4.79	1.98	2.94	0.39	4.10	2.36	2.88	0.21
Value of output ($ ha^{-1})	873	380	549	92.26	737	454	539	57.58
Cost of production ($ ha^{-1})								
Current inputs	121	70	87	15.53	77	64	68	8.19
Labour inputs	189	89	124	24.80	253	162	189	26.80
Power inputs	35	33	34	5.02	38	25	28	4.13
Land rents	272	129	178	44.29	224	153	174	48.25
Total paid-out costs ($ ha^{-1})	250	154	187	36.88	227	172	203	31.32
Total variable costs ($ ha^{-1})	617	321	423	77.63	592	404	459	56.37
Returns above paid-out costs ($ ha^{-1})	623	226	362	69.31	460	282	336	62.63
Gross margin ($ ha^{-1})	256	59	126	43.68	145	50	80	49.54

US$1 = Philippine pesos 26.

Effect of excessive rainfall during the peak seeding period on yields. Earlier research established that most farmers at the study site completed dry-seeding operations at a cumulative rainfall amount of 150 mm (IRRI, 1993). However, excessive rainfall immediately preceding or following seeding could adversely affect crop establishment and yield. In 1992 and 1995, excessive rainfall coincided with the peak seeding period (11–24 June) and hampered crop establishment. In 1992, rainfall amounting to 313 mm during four successive five-day spans during the peak seeding period washed out seeds on many freshly-sown farms. In 1995, rainfall amounting to 174 mm in the 15 d immediately prior to the peak seeding period caused excessively wet field conditions which lasted for 15 d, although rainfall during the peak seeding period was not high. This resulted in low plant density, and consequently low yields, on the farms that were seeded during the peak seeding period in 1995 (Table 2).

The mean rice yield for DSR-H farms in 1994 (4.64 t ha^{-1}) was similar to that in 1995 (4.65 t ha^{-1}). However, 40% of 1994 DSR-H farms were affected by excessive rainfall during the peak seeding period in 1995 and gave low yields. Therefore, they were grouped as DSR-L farms in 1995. Also, the CV of yields of DSR-H farms in 1995 was higher (22%) than in 1994 (16%). The reverse was true for DSR-L farms, where CV of yields was lower (11%) in 1995 than in 1994 (19%). From this it can be hypothesized that higher-yielding farms are more sensitive than lower-yielding farms to the effects of excessive rainfall during or immediately preceding the peak seeding period.

Performance stability of DSR technology

To be an attractive alternative to TPR in rainfed lowlands, DSR should have the potential to perform equally well or better than TPR in years with unfavourable rainfall, but should substantially out-perform TPR in years with favourable rainfall. In this analysis, the DSR system seems to possess that kind of potential, since it can take advantage of the early monsoon rains, establishing the crop earlier and consequently suffering lower drought risk than TPR. Productivity performance of DSR with respect to the variability in rainfall during 1991–95 was analysed. Although a longer period of analysis would have been more meaningful

Table 2. Comparison of yield and selected agronomic parameters for dry-seeded rice in Urbiztondo, Pangasinan, Philippines in the 1994 and 1995 wet seasons.

Year	Yield (t ha^{-1})	Plant density 15–20 DAS† (number m^{-2})	Seed rate (kg ha^{-1})	Nitrogen application (kg ha^{-1})	Weed weight 60 DAS† (g m^{-2})
1994	4.13	490.60	170.55	108.44	59.9
1995	3.06	303.76	174.65	97.77	187.5
S.e.d.	0.17	28.70	10.30	9.90	16.10

†DAS = days after seeding.

for capturing rainfall variability in a stochastic sense, the 1991–95 rainfall data provided interesting variations.

Based on seasonal yield variability of the DSR and TPR subsamples for 1991–95 (only those farms growing either DSR or TPR on the entire farm every season during the period), DSR was slightly more stable (CV = 37%) than TPR (CV = 45%). For both systems, there was no significant difference in the amount of nitrogen (N) applied by the farmers. However, the mean yield of DSR farms was higher than that of TPR farms.

In each year except 1992 farmers growing DSR produced better yields than those who adopted TPR (Fig. 2), the reason for which has been discussed earlier. The lower mean yields of TPR farms were due to drought stress during the reproductive stage of the crop, which was severe in 1995 and caused 1.44 t ha^{-1} difference in mean yields between DSR and TPR farms. For 1991–95, the CV of individual DSR farm yields was between 16 and 37%, with mean seasonal yields between 2.54 and 5.52 t ha^{-1}. On the other hand, the CV of yields of the TPR farms was between 6 and 65%, with mean seasonal yields between 1.32 and 4.26 t ha^{-1}.

To examine the productivity of DSR farms over time, nitrogen use, pre-harvest labour, water deficit and excess water conditions at plant establishment time were regressed against yields, producing the following linear relationship:

$$\begin{aligned} Y = {} & 1093.54 + 15.392N^{***} + 120.295PL^{**} \\ & + 23.445WS - 2.897PL \times WS^{*} - 731.101D^{*} + e \qquad (R^2 = 0.64) \end{aligned}$$

where:

Y = rice yield (kg ha^{-1})
N = nitrogen input (kg ha^{-1})
PL = pre-harvest labour (labour days ha^{-1})

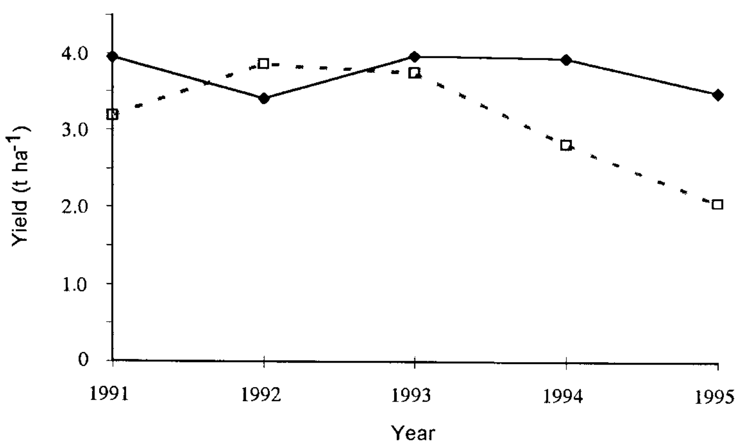

Fig. 2. Mean yield (t ha^{-1}) of farms which grew solely dry-seeded rice (—◆—) or transplanted rice (– –□– –) in Urbiztondo, Pangasinan, Philippines in 1991–95.

WS = water stress (days), estimated as the sum of the number of days in the vegetative and reproductive phases of the crop when the perched water table was more than 30 cm below the soil surface

D = dummy variable for the effect of excessive rainfall on plant population, D = 1 if plant population was significantly reduced due to excessive rainfall, otherwise D = 0.

e = error term

***, **, * = significant at 1, 5, and 10% probability levels respectively.

The model, which is statistically significant and explains 64% of the yield variability in the sample, indicates that the sample farmers were able to obtain reasonable yield response from the managed variables N and PL. Variability in PL was mostly due to variability in weed control (that is, pre- and/or post-emergence herbicide applications and manual weeding), fertilizer application and bund management. PL × WS accounted for the interactive effect of the water deficit on labour demand during the pre-harvest period. Furthermore, the response function also showed that for every kg N applied, rice yield increased by 15.4 kg, *ceteris paribus*, and that for every unit (labour day) increase in labour input in the pre-harvest period, yield increased by 120.3 kg. The significant negative dummy variable indicated yield losses due to the detrimental effect of excessive rainfall on plant population.

It should be noted, however, that this sample of farmers had substantial experience in growing DSR, and thus may have had better weed control and overall crop management; their farms might also have been physically better suited to dry-seeding than other farms in the area. Considering these possible limitations, use of a larger and longer data set is desirable for a more meaningful analysis of DSR yield stability and comparison with TPR.

Management practices and DSR farm productivity

The effects of four important practices (tillage, land-levelling, weed control and bund management) on DSR productivity were analysed.

Tillage. In the study area, tractors with disc harrows and draft animals with mouldboard ploughs were the main power sources. Farmers used these implements in combination or alone, depending on the timing of field operations and available resources (Table 3). Land preparation took less time in 1995 than in 1994 because there were fewer tractors available in the area during 1994. The average duration of land preparation was shorter for the combined implements in 1994 (26 d) and 1995 (17 d). Sole tractor or animal use took about the same time for land preparation in each year. In both years, fields without pre-rice crops were ploughed earlier and had significantly longer (7–8 d) land preparation than fields with pre-rice crops (Table 4). Fields with pre-rice crops had fewer weeds than those which were fallow during the pre-rice season. Thus an effective weed management strategy was to plough the field earlier and prepare the land over a

Table 3. Implements used for ploughing and land preparation time for dry-seeded rice in Urbiztondo, Pangasinan, Philippines in the 1994 and 1995 wet seasons.

	% farms using implement (n = 50)		Land preparation time (d)		
Implement	1994	1995	1994	1995	S.e.d.
Animal	29.0	36.7	33.8	19.8	5.2
Tractor	29.0	30.6	32.3	20.5	7.7
Combination	42.0	32.7	26.4	17.3	3.7
All implements			30.3	19.2	3.1

Table 4. Land preparation time and weed weight at 60 days after sowing for rice and rice/non-rice crop combinations using dry-seeded rice in Urbiztondo, Pangasinan, Philippines in the 1994 and 1995 wet seasons.

Crops	% farms adopting (n = 50)	Land preparation time (d)	Weed weight (g m^{-2})	Yield (t ha^{-1})
		1994		
Rice alone	42	33.2	63.8	4.2
Rice + pre- and post-rice crops	24	25.5	60.3	4.4
S.e.d.		4.20	13.83	0.29
		1995		
Rice alone	56	20.4	234.9	2.9
Rice + pre- and post-rice crops	30	13.0	153.5	3.1
S.e.d.		3.36	29.1	0.21

longer period to remove existing weeds, and/or to grow a non-rice crop before DSR.

There was no significant difference in the effectiveness of weed control among farms using the three different ploughing systems. Moreover, regardless of the type of implement used, there were no significant differences in weed growth between fields with two or three ploughings before harrowing (Table 5).

Weed management. The following four weed species were dominant in the field during the vegetative stage of the rice crop: *Echinocloa colona, Cyperus rotundus, Cynodon dactylon* and *Ischaemum rugosum*. Since weeds are a major reason for low yields in DSR, and farmers invest less in nitrogen if they cannot control weeds adequately, the weed control practices and the nitrogen use of the high and low yield groups of both rice systems were analysed.

Both DSR-H and TPR-H farms used similar amounts of nitrogen; the same was also true for DSR-L and TPR-L farms. In each system, however, H farms used significantly more nitrogen than L farms (Table 6). Both groups of DSR farms

Table 5. Effect of ploughing intensity on weed weight in dry-seeded rice in Urbiztondo, Pangasinan, Philippines in the 1994 and 1995 wet seasons.

Number of ploughings	Weed weight at 60 DAS† ($g\ m^{-2}$) 1994	1995	S.e.d.
2	73	197.9	22.2
3	57	186.6	45.0
S.e.d.	15.80	47.6	

†DAS = days after seeding.

Table 6. Nitrogen fertilizer use and weed control of high- and low-yielding dry-seeded rice and transplanted rice farms, Urbiztondo, Pangasinan, Philippines, 1991–93 wet seasons.

Treatment	Dry-seeded rice High	Low	S.e.d.	Transplanted rice High	Low	S.e.d
Nitrogen ($kg\ ha^{-1}$)	113	56	18.04	92	61	17.49
Weed control:						
Herbicides costs ($\$\ ha^{-1}$)	10	9	4.83	4	4	1.76
% farmers using herbicide alone	36	29		23	19	
Handweeding alone ($\$\ ha^{-1}$)	†	20	15.23	18	8	5.70
% farmers using handweeding alone	0	19		54	26	
Herbicide + handweeding ($\$\ ha^{-1}$)	30	26	10.40	†	16	7.48
% farmers using combination	64	33		0	10	
No weed control (% farmers)	0	19		23	45	

†No farmers did handweeding alone; US$1 = Philippine pesos 26.

spent comparable amounts on herbicides. However, 64% of DSR-H farmers did additional hand-weeding, compared with only 33% of DSR-L farmers. This strategy of combining herbicide application and manual weeding will remain the most effective way of controlling weeds until farmers learn how to control weeds with herbicides alone. Of the DSR-L farmers 19% did not use any weed control measures at all, as opposed to 0% of the DSR-H farmers. Weed control measures were not used by 23% of TPR-H and 45% of TPR-L farmers. This was expected, as the puddling process for TPR provides substantive weed control benefits (Ahmed and Moody, 1982; Sarkar and Moody, 1983). On average, DSR-L farms produced 0.38 $t\ ha^{-1}$ lower yields than TPR-L farms, although the difference was not statistically significant.

Using the 1994–95 data set, use of herbicides (both quantity and types), weed control measures and the effect of pre- and post-rice crops on weed growth in DSR fields were analysed. Farmers used four types of herbicides: butachlor, oxadiazon, 2,4-D, and Advance (butachlor and propanil combination). Butachlor, oxadiazon and Advance are pre- and early post-emergence herbicides, while 2,4-D is a post-emergence herbicide. Most farmers used a combination of pre- or early post-emergence and post-emergence herbicides in 1994 and 1995.

Of the sample farmers, 32% used harrowing (*sagar*) as a mechanical means of weed control. This can be considered the counterpart of rotary weeding in a TPR system. *Sagar* involves dragging an animal-drawn combed harrow in the field during the early vegetative stage of the crop to uproot weeds. As indicated previously, weed weight was significantly less on farms with pre- and post-rice crops than on those growing rice alone, particularly in 1995. This indicated the value of this practice as a weed control measure.

Bund management. Bund management is important for rainwater conservation in the field. Based on the location of bunds with reference to the direction of surface water movement, the 1994–95 sample farms were classified into four types: periphery bunded (PB), periphery/cross-bunded (PCB), cross-bunded (CB) and unbunded (UB).

Periphery bunded (PB). These were farms with bunds on all four sides but none within the farm and, of the sample farms, 24% belonged to this category. The average field slope for these farms was 0.11% and the average bund density was 1381 m ha^{-1}. The periphery bund alone was not sufficient to either prevent runoff or rainwater outflow from the field, or to uniformly distribute water in the farms, which were long and narrow. Compared with the other types of bunded fields, the PB fields had higher WDI and lower nitrogen use, which resulted in lower grain yields.

Periphery/cross-bunded (PCB). Farms with bunds at the periphery and also inside the farm across its general slope. These farms, representing 22% of the total sample, had an average slope of 0.13% and an average bund density of 1463 m ha^{-1}. The cross bunds, in conjunction with periphery bunds, controlled water movement within the farm more effectively than PB alone. The PCB fields had a significantly lower WDI than the fields with only periphery bunds. The combination of lower WDI and higher nitrogen use produced a significantly higher average grain yield (4.42 t ha^{-1}) in PCB fields compared with PB farms (3.58 t ha^{-1}).

Cross-bunded (CB). These were farms with bunds only across the general slope, and usually no bunds along the slope. However, in some cases, these farms were also partially bunded along the slope. This type of bunding was the most common (38% of the sample farms) and had an average field slope of 0.146%. The mean bund density was low (853 m ha^{-1}) due to absence of bunds on the periphery or on the longer sides. Farms with CB gave higher yields and returns than PB or PCB farms, because cross bunds facilitated good water management. Cross-bunding alone was as effective as PCB for retaining water in the field because there was no significant slope across the length of the field. In the sample farms, the CB fields had more bunds than the PCB fields. The appropriate number of cross-bunds for a given field depended on its length and slope.

Unbunded (UB). These farms, which had no bunds either across or along the slope of the fields, were smaller than any of the bunded farms. The average slope of the sample farms within this category was 0.12%. The UB farms had moderate WDI, higher nitrogen use, and similar yields compared with PB farms. The smaller size, better levelling, lower elevation and higher fertilizer use probably offset the disadvantages of these farms' low ability to retain water. Unbunded farms were mostly located towards the bottom of the general toposequence.

Economic aspects of bunds. Using the 1994–95 data set, DSR farms were grouped as high (H)- or low (L)-yielding and then subdivided into those with or without bunds. Only 10% of H farms, as opposed to 21% of L farms, had no bunds. Except for the herbicide butachlor, which was used in higher quantity by H-without-bund fields, there was no significant difference in input use among the groups of farms.

The mean yield of H farms with bunds was significantly higher, 1.96 t ha^{-1} more than L farms with bunds (Table 7). On the other hand, the difference in mean yields of DSR-H farms with and without bunds was not significant. This

Table 7. Comparison of costs and returns of dry-seeded high yielding (DSR-H) and low yielding (DSR-L) farms with and without bunds, in Urbiztondo, Pangasinan, Philippines, in the 1994 and 1995 wet seasons.

	DSR-H		DSR-L	
Cost and return	With bunds	Without bunds	With bunds	Without bunds
Mean yield (t ha^{-1})	4.70	4.26	2.74	2.91
Value of output ($ ha^{-1})	1215	1032	743	818
Cost of production ($ ha^{-1})				
Current inputs	151	192	126	133
Labour inputs	252	324	168	141
Power inputs	72	87	58	67
Land rents	331	305	244	332
Total paid-out costs ($ ha^{-1})	363	477	278	308
Total variable costs ($ ha^{-1})	806	908	596	673
Returns above paid-out costs ($ ha^{-1})	852	555	465	510
Gross margin ($ ha^{-1})	409	124	147	145
Rate of return ($ $$^{-1}$)				
Current inputs	3.71	1.64	2.17	2.10
Labour inputs	2.62	1.38	1.88	2.03
Power inputs	6.70	2.42	3.53	3.16
Land	2.24	1.41	1.60	1.44

S.e.d. 0.167 between yield means of H and L farms with bunds; 0.229 between yield means of H farms with and without bunds; 87.21 between returns above paid-out cost means of H farms with and without bunds; 102.4 between gross margin means of H farms with and without bunds; 48.17 between gross margin means of H and L farms with bunds. US$1 = Philippine pesos 26.

could be due to the effects of lower slope and smaller farm size in the farms without bunds. Furthermore, farmers in both H and L farms without bunds attempted to offset the effects of not using bunds by applying more fertilizer and herbicides for weed control than H farms with bunds. As a result of the higher expenditures on fertilizer and weed control, the mean net returns of H farms without bunds was significantly lower than H farms with bunds. Only 10% of H farms were without bunds, indicating that most farmers who achieved higher yields were using bunds as a measure to improve farm productivity. Both H and L farms with bunds gave higher rates of return to current inputs, power input and land than farms belonging to the same productivity group but without bunds (Table 7).

Land-levelling precision. Better land-levelling is important for achieving uniformity of water depth, good drainage, fertilizer-use efficiency, and crop yield. Yield for DSR was significantly correlated with the precision of land-levelling (Fig. 3). The rate of change in yield due to land-levelling differences was about the same in both years, as indicated by the similar slopes for the 1994 and 1995 regression lines in Fig. 3. The mean standard deviation of land-levelling precision was 8 cm. On average, in 1994 and 1995, a farmer lost 0.93 t ha^{-1} of rice yield due to land-level deficiencies. As discussed earlier and indicated in Fig. 2, the 1995 yields were lower than those in 1994 because of significantly lower plant density and higher weed growth in 1995.

The influence of levelling precision on field water status is shown in Fig. 4. In the study area, fields with higher levelling precision showed a significantly lower seasonal water stress, which was represented by the WDI. About 44% of the sample farms in the study area had two or more plots per farm. WDI did not vary significantly between larger multi-plot fields (> 0.5 ha) and smaller single-plot fields (< 0.3 ha), but in the latter rice yield was significantly lower. The division

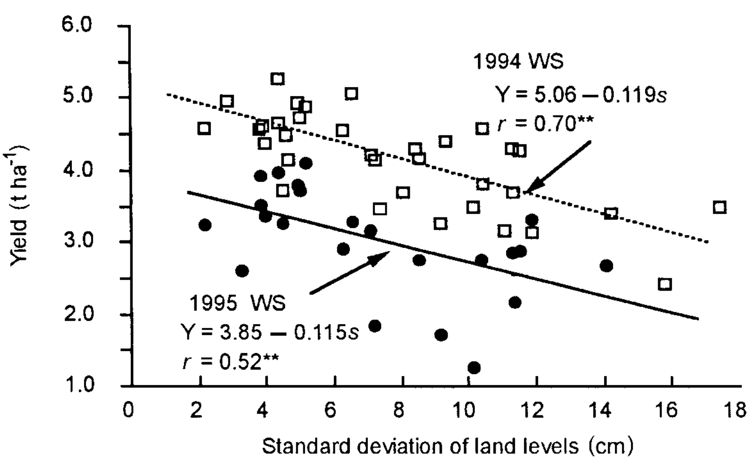

Fig. 3. Relationship between land-levelling precision and grain yield in dry-seeded rice farms in Urbiztondo, Pangasinan, Philippines in the 1994 (□) and 1995 (●) wet seasons (WS); s = standard deviation.

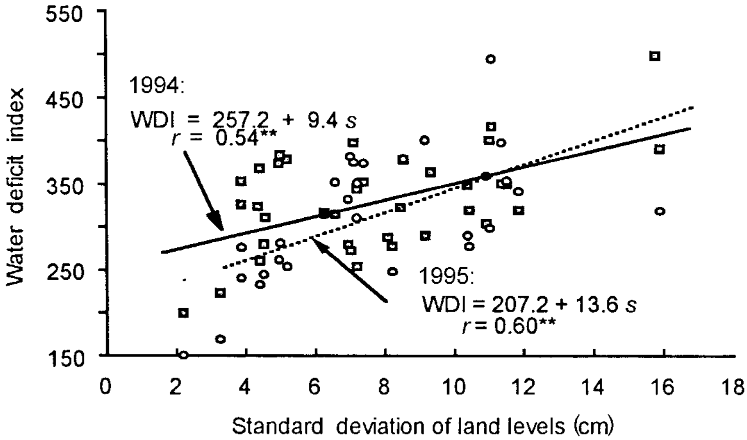

Fig. 4. Relationship between land-levelling precision and water deficit index (WDI) in dry-seeded rice farms in Urbiztondo, Pangasinan, Philippines in the 1994 (□) and 1995 (○) wet seasons. *s* = standard deviation.

of large and medium fields into a number of plots significantly reduced their length and improved levelling precision, leading to better water control in the field and higher yields.

The correlation between standard deviation and plot area was highly significant (Fig. 5), indicating that as the plot area increased, land-levelling precision decreased. Similar observations on rice fields have been made by other researchers for rice fields in other countries (Vijaylakshmi, 1987; Murugaboopathi *et al.*, 1991; Anbumozhi and Koga, 1993). The result implies that, to achieve the required levelling precision for better water control, a large field should be divided into a number of plots, the number depending upon the slope of the farm. As observed in

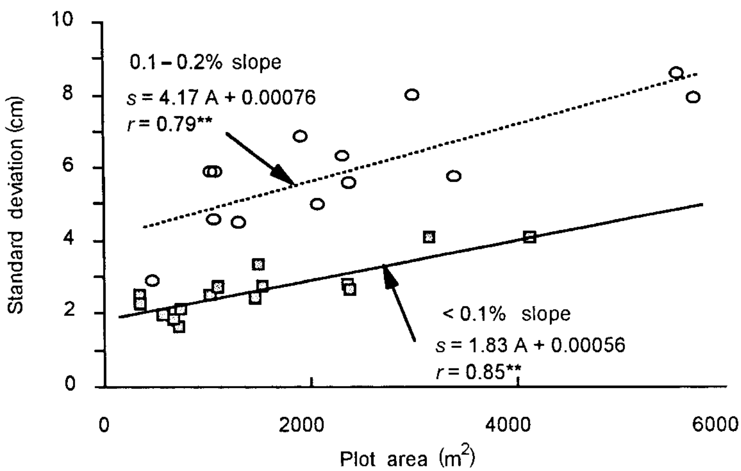

Fig. 5. Relationship between the standard deviation (*s*) of land levels and plot area (A) of sample farms for two different slope groupings, 0.1–0.2% slope (○) and <0.1% slope (▨) in Urbiztondo, Pangasinan, Philippines in the 1994 wet season.

some of the sample farms, a standard deviation value of $s = 5$ cm could be practically maintained by farmers in plots with slope up to 0.2%. This value may be used as a criterion in dividing a field into multiple plots.

CONCLUDING COMMENT

The productivity of DSR can be improved through effective weed control, land-levelling and bund management. From the five-year data set, DSR was found to have slightly higher yield stability than TPR, which makes it an attractive alternative to transplanted rice. However, analysis with more samples and a longer period of time is needed. More research on developing the methodology for assessing yield stability aspects of DSR in different environments is also needed. Although findings from this study relate to specific site conditions, they are generic in nature and have wider applicability.

Acknowledgements. The authors would like to acknowledge the assistance of Dr K. Moody, Mr D. Navarez and Mr L. E. Estorninos Jr, who provided the data on weed weight and weed species used in this paper.

REFERENCES

Ahmed, N. U. & Moody, K. (1982). Weeds in cropping systems as affected by landscape position and weeding regimes. V. Comparison between the first crop grown in different fields. *Philippine Agriculturist* 65:367–375.

Anbumozhi, V. & Koga, K. (1993). *Land-levelling Accuracy of Paddy Fields in Thailand. Irrigation Engineering and Rural Planning 25.* The Japanese Society of Irrigation, Drainage and Reclamation Engineering, Department of Agricultural Engineering, University of Tokyo.

De Datta, S. K. & Kerim, M. S. A. A. A. (1973). *Water and Nitrogen Economy in Rainfed Rice on Puddled and Nonpuddled Soils. International Rice Research Conference.* Los Baños, Laguna, Philippines: IRRI.

De Datta, S. K., Garcia, F. V., Abilay Jr, W. P. & Alcantara, J. M. (1988). *Yield Constraints and Fertilizer Management in Shallow Rainfed Transplanted and Broadcast Seeded Lowland Rice in the Philippines. International Rice Research Institute Research Paper Series 132.* Los Baños, Laguna, Philippines: IRRI.

IRRI (1992). *Program Report for 1991.* Manila, Philippines: International Rice Research Institute.

IRRI (1993). *Program Report for 1992.* Manila, Philippines: International Rice Research Institute.

IRRI (1995). *Program Report for 1994.* Manila, Philippines: International Rice Research Institute.

Murugaboopathi, C., Tomita, M., Yamaji, E. & Koide, S. (1991). Prospect of large-sized paddy field using direct seeding supported by subsurface irrigation system. *Transactions American Society of Agricultural Engineering* 34:2040–2046.

Sanchez, P.A. & Bradfield, R. (1970). *Puddling Tropical Rice Soils. II. Interactions with Water Levels. International Rice Research Conference.* Los Baños, Laguna, Philippines: IRRI.

Sarkar, P.A. & Moody, K. (1983). Effects of stand establishment techniques on weed population in rice. In *Weed Control in Rice*, 57–71. Manila, Philippines: International Rice Research Institute.

Small, L. E., Capule, C. & Oallares, M. (1981). *An Index to Evaluate the Effect of Water Shortage on the Yield of Wetland Rice. International Rice Research Institute Research Paper Series 70.* Los Baños, Laguna, Philippines: IRRI.

Taylor, H. M. (1972). Effects of drying on water retention of a puddled soil. *Soil Science Society of America Proceedings* 36:972–973.

Vijaylakshmi, K. (1987). Rainwater management in drylands. In *Technological Advances in Dryland Agriculture*, 19–45 (Eds S. P. Singh, K. Vijaylakshmi, P. A. O'Sullivan & G. Shaw). Hyderabad, India: Central Research Institute for Dryland Agriculture.