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Water, tillage and weed management options for wet seeded rice in the Philippines

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Abstract

The recent shift from transplanted to wet seeded rice (*Oryza sativa* L.) in South East Asia has resulted in major weed problems which require more labour and energy for their control. Field experiments were conducted during 1994–1996 on a Chromic Vertisol in central Luzon, the Philippines, to study the effect of water, tillage and herbicide levels on total water use, weed growth and yield of wet seeded rice. The treatments included three water regimes (i) shallow-water ponding (5 ± 2 cm) throughout the crop growth period (W1), (ii) shallow-water ponding until panicle initiation and then saturated soil (W2), and (iii) saturated soil (W3); two tillage levels (i) one ploughing + two harrowings (T1), and (ii) two ploughings + two harrowings (T2); and three herbicide levels, pretilachlor at a rate of (i) 0.30 kg a.i. ha^{-1} (H1) and (ii) 0.15 kg a.i. ha^{-1} (H2), and (iii) no herbicide (H3). Water ponding effectively suppressed weeds, irrespective of the herbicide dose applied. Both, the herbicide levels (H1 and H2) were equally effective and produced statistically similar rice yields. More intensive tillage (T2), produced significant positive effect in controlling weeds in the dry season. The T2-W1-H1 combination produced the highest rice yield. Saturated soil (W3) saved about 40% of water compared to continuous shallow ponding (W1) and produced statistically the same rice yield when weeds were controlled by herbicide. Proper use of herbicide can thus substitute the excessive water-consuming practice of continuous submergence in rice fields.

Keywords: Herbicide; Tillage intensity; Water regime; Wet seeded rice; Weed growth

1. Introduction

The warm temperature and high humidity conditions of tropical Asia favour year round luxuriant growth of almost all weed species (De Datta, 1981). In wet seeded rice (rice established by direct seeding of pre-germinated seeds on the puddled soil), where weed control is more difficult and expensive than in transplanted rice (De Datta, 1986; Baltazar and De Datta, 1992), a good land preparation, effective water control and chemical weed control are often considered as cost-effective alternatives to manual weeding (Bernasor and De Datta, 1988). Increased tillage suppresses weed growth (Janiya and Moody, 1982) and increases rice yields (Kuipers, 1975). Controlled flooding is a traditional method of weed control in rice culture (Matsunaka, 1983), but the degree of water

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control needed for weed control is still not fully understood in many countries of Asia and Africa (Moody and Cardova, 1985).

Most past studies in weed control in tropical Asia have been confined to evaluation of the effects of herbicides, tillage and water, but without consideration of their interactions (Bhan, 1983; Baltazar and De Datta, 1992). Few studies have been conducted on the dynamics of weed populations due to variable water regimes, use of different tillage intensities, change in the crop establishment method or herbicide use in wet seeded rice. Such information can prove valuable in predicting future weed problems and is indispensable in determining weed control strategies for wet seeded rice culture which is finding increasing popularity.

This paper presents the results of studies conducted for four consecutive seasons during 1994–1996. The objectives of the study were to determine the effects of different water regimes, tillage intensities and herbicide doses on total water use, weed population, and yield of wet seeded rice in a typical farmer's field in Central Luzon, the Philippines.

2. Materials and methods

2.1. Experimental site and treatments

The experimental site was a farmer's field in barangay (Village) Baluga, Talavera municipality, Nueva Ecija Province which is the prime rice growing region of the Philippines. The soil was a Chromic Vertisol, pH 5.92, cation exchange capacity of 18 cmol $(p^+)\ kg^{-1}$ and organic carbon content of 8.3 $g\ kg^{-1}$ at 0–0.30 m depth. Selected soil characteristics are summarized in Table 1. The daily rainfall and evaporation (US class A open pan) rates measured during the entire study period at a weather station set up at the experimental site are presented as weekly totals in Fig. 1.

The treatments included three water levels: field flooded (5 ± 2 cm) throughout crop growth (W1); field flooded until panicle initiation (PI) and then saturated soil (W2); and saturated soil throughout crop growth (W3). The two tillage levels were as follows: (i) one ploughing + two harrowings (T1); and (ii) two ploughings + two harrowings (T2). The three herbicide levels used were: (i) pretilachlor (sofit) at the recommended rate of 0.30 kg a.i. ha^{-1} (H1); (ii) pretilachlor at half the recommended rate of 0.15 kg a.i. ha^{-1} (H2); and (iii) no herbicide (H3). All possible combinations of water, tillage and herbicide rates were replicated three times in a split-plot design, with water and tillage in main plots (15 × 13 m) and herbicide rates in subplots (5 × 13 m).

The experimental site had access to irrigation supplies, and had grown two rice crops each year, one during the wet and one during the dry season for 50

Table 1
Soil characteristics of the experimental site (0–0.30 m depth)

Sand ($g\ kg^{-1}$)	348
Silt ($g\ kg^{-1}$)	416
Clay ($g\ kg^{-1}$)	236
pH (1 : 25 w/v H_2O)	5.92
Saturated hydraulic conductivity ($m\ s^{-1}$)	5.66×10^{-7}
Bulk density ($Mg\ m^{-3}$)	1.33 ± 0.003
Cation exchange capacity (cmol $(p^+)\ kg^{-1}$)	18.0
Organic carbon ($g\ kg^{-1}$)	8.3
Total nitrogen ($g\ kg^{-1}$)	7.0
Olsen phosphorus ($mg\ kg^{-1}$)	5.0
Exchangeable potassium (cmol $(p^+)\ kg^{-1}$)	0.2
Exchangeable calcium (cmol $(p^+)\ kg^{-1}$)	9.3

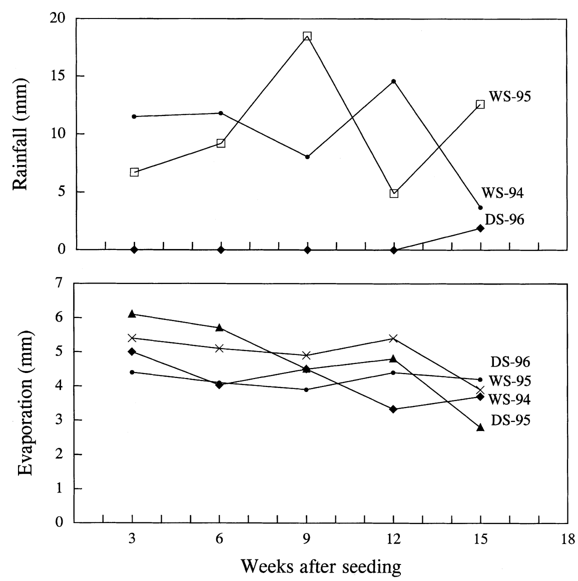

Fig. 1. Rainfall and evaporation during WS-1994, DS-1995 (no rainfall occurred), WS-1995 and DS-1996 at Baluga, Talavera, Neuva Ecija, Philippines.

years. The site was given minor land shaping before laying out the plots to facilitate the construction of channels and dykes for managing water drawn from the Upper Pampanga River Integrated Irrigation System (UPRIIS). The soil was flooded before imposing the tillage treatments. The tillage was done with a small (11.9 kW) tractor. The maximum depth of tillage in T2 was 0.18 m. The main plots were separated from each other by a buffer margin of 1.5 m width, which accommodated a 50-cm wide irrigation channel between two 50-cm wide dykes.

Pre-germinated seeds of rice (cv. IR-64) were broadcast on to the puddled and drained soil on 11 and 17 July, for the 1994 and 1995 wet season (WS), respectively. The dry season (DS) seeding dates were 11 January 1995 and 31 January 1996. The soil received the recommended fertilizer rates of 120 : 26 : 50 (kg ha^{-1}) as N : P : K. All of the P and K was applied before the final land preparation. Nitrogen (N) was applied in three equal splits at 10, 20 and 30 days after seeding (DAS). The herbicide was applied at 1 DAS. The first application of irrigation water (5 cm) was made at 3 DAS to all plots, thereafter irrigation was applied according to the treatments. The four consecutive rice crops were harvested on 17 October, 1994 (WS), 24 April, 1995 (DS), 23 October, 1995 (WS) and 17 May, 1996 (DS).

2.2. Weed sampling

In the first season (1994 WS), weeds were sampled only at 45 DAS at three randomly selected spots (1 m^2 area) in each plot. During the subsequent seasons weed samples were taken at 30, 45 and 60 DAS to identify weed species and to determine their dry weights.

2.3. Water management and crop yield

The amount of water applied to each plot was measured using a triangular weir (V-notch) as follows:

$$Q = 0.0138h^{2.48}$$

where Q is the discharge through the weir in l s^{-1}, and h the weir head in cm.

The percolation rate and the perched (or actual) water table fluctuation in each plot were measured with sloping gauges (International Rice Research Institute, 1982) and perforated plastic pipes installed at up to 1.5 m depth, respectively.

The daily evapotranspiration rate (ET) was calculated using the following regression equations, which were developed for Central Luzon, the Philippines, by Kampen and Levin (1970):

(a) Wet season

$$\text{Vegetative stage ET} = 0.8E + 0.3 \quad (1)$$

$$\text{Reproductive stage ET} = 0.9E + 0.2 \quad (2)$$

(b) Dry season

$$\text{Vegetative stage ET} = 0.8E + 0.5 \quad (3)$$

$$\text{Reproductive stage ET} = 0.9E + 0.5 \quad (4)$$

Here, E is the daily Class A pan evaporation.

The yield was measured by harvesting a 4×10 m^2 area from each plot leaving the boarders. The water productivity was calculated by dividing the grain yield (kg ha^{-1}) obtained in each treatment with water used (mm) in the treatment.

3. Results and discussion

3.1. Percolation and seepage

Percolation and seepage for the first two seasons (WS-1994 and DS-1995) were measured only for the ponded treatments, which did not give a complete comparison of all the treatments. However, for the latter two seasons (WS-1995 and DS-1996), comparisons were made for all the treatment combinations and revealed that increased tillage intensity (T2) significantly decreased percolation + seepage compared to less intensive tillage (T1) at most of the sampling dates (Table 2). Sharma and De Datta (1985) have also shown decreased percolation with an increase in tillage intensity in Mahaas clay soil in the Philippines.

Significant differences were also observed among different water regimes for percolation + seepage values (Table 2). In the initial stages and up to eight weeks after seeding (WAS), the ponded-water treatments (W1 and W2) had, statistically, significantly higher percolation + seepage compared to saturated soil (W3). After 8 WAS, i.e. at the panicle initiation

Table 2
Changes in percolation plus seepage during WS-1995 and DS-1996

Season	Weeks after planting	Treatments						LSD[f]		ET[g]
		W1[a]T1[b]	W1[a]T2[d]	W2[c]T1[b]	W2[c]T2[d]	W3[e]T1[b]	W3[e]T2[d]	tillage	water	
WS-95	2	17.7	17.1	16.9	17.0	10.1	9.4	ns[h]	3.1	4.5
	4	24.0	21.9	18.1	16.4	7.5	6.2	ns[h]	7.8	4.7
	6	20.3	16.7	15.9	16.4	7.7	8.2	1.2	6.1	4.3
	8	16.1	16.9	6.9	9.7	8.4	6.7	1.3	5.9	5.3
	10	11.9	11.4	5.3	5.6	5.1	6.0	ns[h]	5.5	4.4
	12	6.6	4.8	4.5	3.7	2.1	1.7	ns[h]	ns[h]	4.2
	14	1.4	1.1	0.0	0.4	0.1	0.0	ns[h]	ns[h]	5.3
DS-96	2	22.1	21.5	22.0	20.5	16.5	14.2	ns[h]	2.5	5.2
	4	19.7	22.5	22.5	17.6	13.5	12.0	ns[h]	3.2	5.8
	6	21.7	20.4	18.6	16.5	12.4	10.4	1.5	3.1	5.8
	8	17.4	14.6	13.5	12.0	10.6	9.0	1.3	2.1	5.2
	10	12.3	11.4	8.4	7.2	6.2	6.0	ns[h]	ns[h]	4.6
	12	11.5	11.6	5.6	4.5	4.0	2.5	ns[h]	ns[h]	5.1
	14	7.8	5.5	4.6	3.1	3.0	1.8	ns[h]	ns[h]	5.8

[a] Shallow flooding throughout crop growth.
[b] One ploughing + two harrowings.
[c] W1 until panicle initiation, then saturated soil.
[d] Two ploughings + two harrowings.
[e] Saturated soil.
[f] Least significant difference.
[g] Daily evapotranspiration rate.
[h] Not significant.

stage when W2 plots were also kept saturated, the percolation + seepage in these plots decreased and became similar to W3 (saturated) plots. However, at this stage and up to 12 WAS, ponded plots (W1) continued to have statistically higher percolation + seepage compared to W2 and W3 (at this stage both saturated) plots. After 12 WAS, i.e. at the terminal drainage (rice fields are drained near maturity), the differences in percolation + seepage among different treatments were not significant.

Reduction in percolation + seepage by using improved practices like intensive tillage (T2) or keeping the soil saturated (W3) can substantially reduce total water use. However, some researchers (De Datta, 1981; Hasegawa et al., 1985) suggest that moderate percolation rate (10–25 mm day^{-1}) is essential for obtaining high yields of wetland rice because it removes phytotoxins and supplies oxygen to the rhizosphere and enhances root activity. However, high percolation increases water loss and may cause high rate of leaching of soil nutrients.

3.2. Water-table dynamics

As the experimental site was a part of large flat area and not close to natural streams or drainage ways, the depth of the perched ground water table was assumed to be influenced only by the treatments. During the wet season (Fig. 2), up to 8 WAS, the water table remained within ±0.15 m of the surface. Beyond 8 WAS, its depth steeply increased irrespective of water or tillage treatments. However, the ponded plots (W1 and W2, up to panicle initiation) maintained (Fig. 2) a shallower water table compared to saturated plots (W3, and W2 after panicle initiation). This indicated that the perched water-table depth was determined by the amount of water applied at the surface.

A more intensive tillage (T2) maintained (Fig. 2) a shallower water table compared to less intensive tillage (T1). This indicated less percolation + seepage losses in T2 compared to T1. Also, repeated tillage, as in T2, is known to destroy aggregates, eliminates water transmitting pores, and align soil particles to

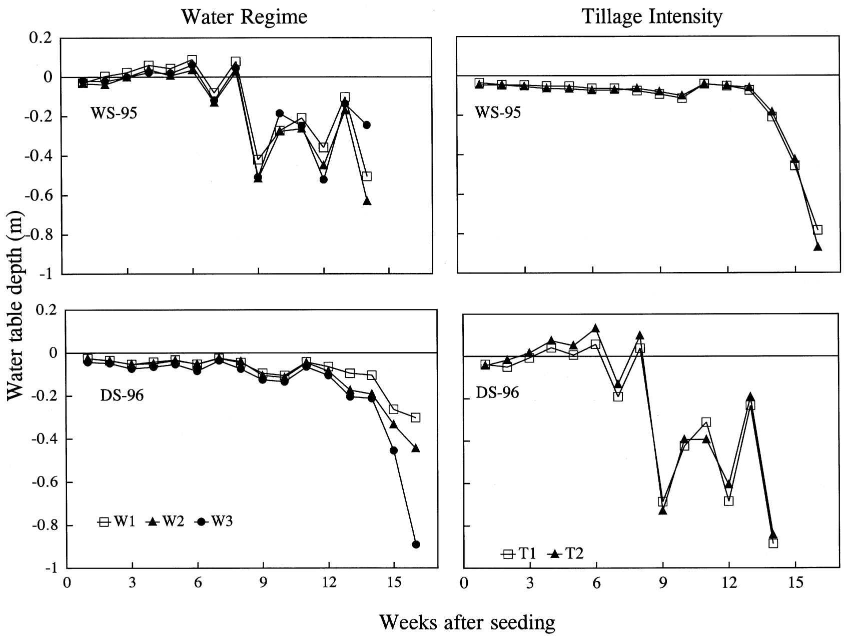

Fig. 2. Water-table dynamics as affected by water regime and tillage intensity during WS-1995 and DS-1996. Legend: W1, shallow flooding throughout the crop growth; W2, W1 until panicle initiation, then saturated soil; and W3, saturated soil.

form a semi-impervious denser soil layer at the base of ploughing depth (Bodman and Rubin, 1948; Sharma and De Datta, 1985).

During the dry season (Fig. 2), the perched water table remained within the upper 0.17 m of soil surface up to 12 WAS. Beyond 12 WAS, its depth steeply increased to 0.80 m. This would mean more water was required during the DS compared to WS. Treatment differences were in the same pattern as that of wet season. However, there was no mid-season increase in water table depth as was observed during the wet season. The probable reason for a mid-season increase in water-table depth was the temporary reduction in rains, something not unusual in this part of monsoonal Asia.

3.3. Water use

During the first season (WS-1994), the water used for land preparation was the same (200 mm) for all plots as land was prepared before the treatments were imposed. However, in the subsequent seasons during land preparation, maximum water was used in the saturated soil with intensive tillage (W3T2). This happened because, compared to others, these plots developed deeper and wider cracks after the harvest of the previous season crop due to rapid and excessive desiccation of soil.

Less amount of water was used (Table 3) in intensive tillage (T2) compared to less intensive tillage (T1). For example, during WS-1994, W1T1 and W2T1 (ponded-water treatments with less intensive tillage) water usage was, respectively, 84 and 69 mm more than that in W1T2 and W2T2 (ponded-water treatments with more intensive tillage). The difference was higher during DS-1995. In saturated plots (W3), the differences in water usage between tillage treatments were statistically significant in the latter two seasons, i.e. WS-1995 and DS-1996. Low water use in intensive tillage (T2), compared to the less intensive tillage system, can be attributed to lower percolation + seepage in T2 compared to T1. The effect of water regimes on water use followed the trend: continuously ponded (W1) > continuously ponded until PI (W2) > saturated plots (W3).

3.4. Water-use efficiency

In general, water-use efficiency was greater (Table 3) in saturated plots (W3) compared to flooded

Table 3
Water use and water-use efficiency of rice (IR-64) during WS-1994, DS-1995, WS-1995 and DS-1996 at Baluga, Talavera (Nueva Ecija), Philippines

Treatment[a]	Water use (Ir + Rn) (mm)				Water-use efficiency (kg ha^{-1} mm^{-1})			
	WS-1994	DS-1995	WS-1995	DS-1996	WS-1994	DS-1995	WS-1995	DS-1996
W1T1H1	2220	2090	2280	2120	3.31	4.05	1.91	1.57
W1T1H2	2220	2090	2280	2120	3.28	3.83	1.78	1.66
W1T1H3	2220	2090	2280	2120	2.95	3.27	1.20	1.07
W1T2H1	2050	1890	2050	2100	2.65	4.53	2.02	1.94
W1T2H2	2050	1890	2050	2100	3.36	4.40	1.93	1.69
W1T2H3	2050	1890	2050	2100	3.38	3.76	1.34	1.30
W2T1H1	1980	1970	2010	2050	3.69	3.97	2.26	1.65
W2T1H2	1980	1970	2010	2050	3.45	3.96	2.27	1.75
W2T1H3	1980	1970	2010	2050	2.83	3.34	1.54	1.24
W2T2H1	1840	1710	1860	2020	3.66	4.62	2.46	1.94
W2T2H2	1840	1710	1860	2020	3.73	4.58	2.21	1.75
W2T2H3	1840	1710	1860	2020	3.07	4.14	1.69	1.01
W3T1H1	1630	1740	1980	1840	4.00	3.77	1.54	1.48
W3T1H2	1630	1740	1980	1840	3.86	3.71	1.58	1.37
W3T1H3	1630	1740	1980	1840	3.43	1.59	1.30	1.10
W3T2H1	1590	1510	1660	1700	4.17	4.72	2.17	1.65
W3T2H2	1590	1510	1660	1700	4.08	4.67	2.23	1.56
W3T2H3	1590	1510	1660	1700	3.30	2.18	2.06	1.09
LSD[b](0.05)	150	200	200	110	0.12	0.16	0.15	0.08

[a] W1, shallow flooding throughout crop growth; W2, W1 until panicle initiation, then saturated soil; W3, saturated soil; T1, one ploughing + two harrowings; T2, two ploughings + two harrowings; H1, pretilachlor at a rate of 0.30 kg a.i. ha^{-1}; H2, pretilachlor at a rate of 0.30 kg a.i. ha^{-1}; and H3, no herbicide.
[b] Least significant difference.

treatments (W2 and W3). This was due to less water used for W3 to maintain yields of rice similar to or slightly lower than those of W1 and W2. Intensive tillage (T2) also used less water than less intensive tillage (T1), hence the water-use efficiency was greater in T2 compared to T1. Use of herbicide also affected water-use efficiency. Higher level of herbicide resulted in higher yield and, hence, higher water use efficiency. In the absence of herbicide (H3), water-use efficiency was the lowest because of the low level of yields.

3.5. Weed growth

In all seasons, water ponding (W1) effectively suppressed the weed population, regardless of the use of herbicide (Fig. 3). Similar findings have been reported by other researchers for Asian rice culture (Kim, 1980; Pablico and Moody, 1982; Nartsomboon and Moody, 1988). Herbicides, on the other hand, effectively controlled weeds at both the levels (H1 and H2) under all water regimes. Under no-herbicide condition (H3), there was significantly higher weed growth in saturated plots (W3) compared to flooded plots (W1 and W2). This indicated that, if the soil is to be kept at saturation level in order to save irrigation water, herbicide has to be used properly to achieve weed control. Tabbal et al. (1992) have also obtained similar results in terms of water saving by maintaining saturated soil.

The effect of tillage was observed at no herbicide (H3) level [where weed weight was significantly reduced by more intensive tillage (T2) compared to less intensive tillage (T1)] only because the weed population in the other two herbicide levels (H1 and H2) was very low (Fig. 3). At both levels of tillage, herbicide at full and half doses (H1 and H2) were equally effective. Bernasor and De Datta (1988) observed that proper tillage is essential for the effectiveness of herbicides, while Pablico and Moody (1982) concluded that tillage can only enhance the effectiveness of certain kind of herbicides.

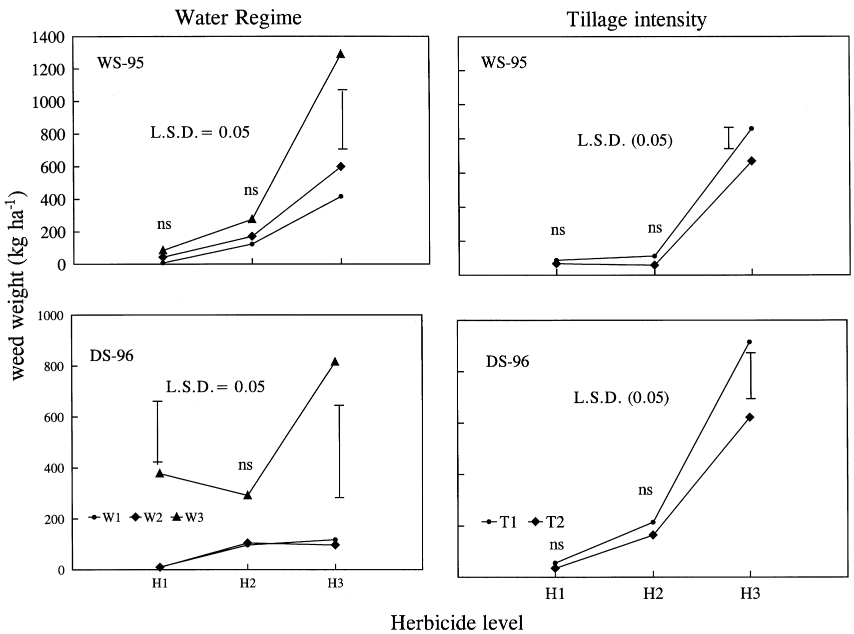

Fig. 3. Effect of water regime and tillage intensity on weed weight at different herbicide levels during WS-1995 and DS-1996. Legend: W1, shallow flooding throughout crop growth; W2, W1 until panicle initiation, then saturated soil; W3, saturated soil; H1, pretilachlor at a rate of 0.30 kg a.i. ha^{-1}; H2, pretilachlor at a rate of 0.15 kg a.i. ha^{-1}; and H3, no herbicide. Bars give LSD (least significant difference) at 0.05.

Table 4
Mean rice grain yield (Mg ha^{-1}) during seasons

Treatment[a]	Season				Overall means (four crops)
	WS-1994	DS-1995	WS-1995	DS-1996	
(a) *Main plot*					
W1[a]	7.09	7.89	3.66	3.22	5.46
W2[b]	6.50	7.49	4.00	3.16	5.29
W3[c]	6.11	5.54	3.23	2.42	4.33
LSD(0.05)	0.76	1.65	0.41	0.31	0.74
T1[d]	6.59	6.81	3.56	2.87	4.96
T2[e]	6.54	5.20	3.70	3.00	4.61
LSD[i](0.05)	ns[j]	ns[j]	ns[j]	ns[j]	ns[j]
(b) *Subplot*					
H1[f]	7.00	7.74	4.04	3.36	5.54
H2[g]	6.77	7.57	3.91	3.22	5.37
H3[h]	5.92	5.61	2.94	2.22	4.17
LSD[i](0.05)	0.32	0.98	0.22	0.23	0.41

[a] Shallow flooding throughout crop growth.
[b] W1 until panicle initiation, then saturated soil.
[c] Saturated soil.
[d] One ploughing + two harrowings.
[e] Two ploughings + two harrowings.
[f] Pretilachlor at a rate of 0.30 kg a.i. ah^{-1}.
[g] Pretilachlor at a rate of 0.15 kg a.i. ha^{-1}.
[h] No herbicide.
[i] Least significant difference.
[j] Not significant.

3.6. Rice yield

Higher grain yields of rice were obtained during WS-1994 and DS-1995, but yields were low during the two subsequent seasons due to stem borer attack which could not be controlled even with insecticides (Table 4). The highest yields were obtained under continuously flooded (W1) and lowest under saturated (W3) water regime in all the seasons. Generally, the yield differences between W1 and W2 were not significant. Yield differences between T1 and T2 tillage levels were not significant in any of the seasons of the study. Rice grain yields under recommended level of herbicide (H1) were significantly higher than under no herbicide (H3), but were in general at par with half the recommended level (H2). The lower yields under W3 H3 treatment combinations were most probably due to higher weed infestation in these plots. Some earlier studies in transplanted rice conducted in the Philippines also reported significant yield reductions under saturated soil without herbicide application (Janiya and Moody, 1982; Tabbal et al., 1992).

4. Conclusion

In wet seeded rice, keeping the soil saturated throughout the growing season saved >40% water as compared to the standard practice of continuous shallow flooding. The greater weed problem generally associated with the saturated water regime can be overcome by using herbicide at appropriate rates. Increase in tillage intensity reduced water loss through percolation + seepage and also weed growth. In general, saturated soil with appropriate herbicide application and increased tillage intensity resulted in significantly higher water use efficiency.

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