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Effect of Winter Weeds on Growth and Yield of Direct-Seeded Rice in No-tillage Dry Paddy Field

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Abstract : The effects of winter weeds on the growth and yield of direct-seeded rice (*Oryza sativa* L. cv. Akebono) were evaluated in a no-tillage dry paddy field where *Alopecurus aequalis* Sobol. var. *amurensis* (Komar.) Ohwi was uniformly dominant, in Kurashiki, Okayama, Japan, in 1994 and 1995.

Winter weeds significantly inhibited the growth and spikelet production of rice plants as compared to those in the control plots, which were established by herbicide application. The reduction in the spikelet number finally resulted in a 12.6 to 15.6% yield reduction, although the percentage of ripened grains of rice increased somewhat because of the inhibition of the spikelet number by winter weeds. Rice yields in the weedy and control plots increased in different ways according to the increase in straw weight. The number of spikelets on the rice plants in the control plots increased as straw weight increased. In contrast, the percentage of ripened grain on the rice plants in weedy plots increased as straw weight increased. A higher rate of fertilizer greatly recovered the growth and yield of rice in weedy plots. This result suggests that the basal dressing of fertilizer at a higher volume would reduce the frequency of herbicide application for winter weeds.
Key words : Direct sowing culture of paddy rice, Fertilizer, No-tillage, Rice, Winter weeds, Yield, Yield components.

不耕起乾田直播栽培における水稲の生育と収量に及ぼす冬雑草の影響 : 伊藤松雄・高橋道彦（四国学院大学教養部）

要　旨 : 1994 年と 1995 年に岡山県倉敷市にあるスズメノテッポウが優占する不耕起乾田直播水田において，水稲（品種アケボノ）の生育と収量に及ぼす冬雑草の影響を調査した．水稲の生育は冬雑草によって著しく抑制され，またその単位面積当たりの穎花数も著しく減少した．冬雑草の存在により水稲の穎花数が制限されたために登熟歩合は高くなったものの，収量では 12.6 から 15.6%の減収となった．除草区および雑草区ともに藁重が増大するにつれて収量も増大したが，その様式は異なった．除草区の水稲では藁重の増加が穎花数を増加させ，雑草区の水稲では藁重の増加により登熟歩合が増大した．また，施肥量の増加によって雑草区の水稲の生育ならびに減収が改善されたことから，施肥量を増大することによって冬雑草防除のための除草剤の処理回数を減少させうる可能性が示唆された．
キーワード : 乾田直播栽培，収量，収量構成要素，水稲，肥料，不耕起，冬雑草．

No-tillage production system in rice (*Oryza sativa* L.) has received attention in Japan because it saves time and labor before planting[2,10,11]. In a direct sowing culture of paddy rice on a well-drained paddy field (here after called DSC), another technical advantage is also expected from no-tillage. The compact soil in no-tillage fields sustains a heavy seeder under wet conditions, resulting in successful planting on schedule, even in rainy weather[11]. Weed management in no-tillage rice field largely depends on herbicides because the absence of tillage allows weeds to grow without restraint. Three to four applications of post-emergence herbicides before irrigation are required for weed management in no-tillage DSC[3,5]. Non-selective post-emergence herbicides are sprayed once or twice to control winter weeds before planting, while selective post-emergence herbicides are applied for summer weed control after planting. If winter weeds did not affect rice growth and yield, herbicide applications for winter weed control could be eliminated because winter weeds die naturally before summer. However, preliminary observations indicated that winter weeds reduced rice growth and yield under no-tillage conditions[4]. It was observed that the establishment of rice seedlings under weedy conditions was as good as that in the site where winter weeds were controlled, although their emergence time was somewhat delayed by winter weeds. Some studies have focused on the yield reduction of rice by summer weeds in conventional DSC[9,12,13]. Others have discussed the effect of the heavy trash of previous rotational crops on the growth and yield of rice and corn (*Zea mays*

L.) under no-tillage conditions[1,7,8]. However, few reports exist on the interference of winter weeds with the yield of rice in no-tillage. This study focused on the growth and yield of rice rather than the establishment of rice seedlings to elucidate how the established rice plants were affected by winter weeds. Further, potentiality of rice cultivation without winter weed control under no-tillage conditions will be also discussed.

Materials and Methods

Field experiments were carried out in a farmer's no-tillage rice field in Kurashiki, Okayama, Japan in 1994 and 1995. The rice field had been managed with no-tillage for two years before the experiments. *Alopecurus aequalis* Sobol. var. *amurensis* (Komar.) Ohwi uniformly dominated whole experimental plots. Seeds of Akebono (one of the recommended rice variety in Okayama) were drilled at 30cm row spacing with a no-tillage seeder (PFT-6 by Minoru Sangyo) on May 15, 1994 and on May 21, 1995. Rice seeds were sown at a depth of two to four cm.

Slow release fertilizer, LPS 140E80 (N, P, K; 14, 14, 14%), equivalent to 60kg ha^{-1} of nitrogen was use to dress over the whole experimental field just before planting. The field was irrigated on June 23, 1994, and on June 26, 1995. Summer weeds which had started emerging from early May were perfectly controlled by the mixture of quinclorac and bentazone applied at 0.4 + 2.0kg a.i. ha^{-1} before irrigation to eliminate their effects on rice growth. Rice plants were harvested on October 20, 1994 and on October 28, 1995 for yield analysis. Other field management was in accordance with the farm operation guidance in Okayama. A conventional tillage site was established as the standard tillage system near by the no-tillage site. Management of the conventional tillage was just the same as the no-tillage experiment, except for tillage.

The summer of 1994 was very hot and dry (about 30% less precipitation than the average year), but the precipitation and the temperature during a growing season in 1995 were about average in the preceding three decades.

1. Effect of winter weeds on rice yield

Experimental plots sized at 25m² (5m × 5m) were randomly established with three replications. To make the control plots weed-free, a non-selective post-emergence herbicide, isopropylamine salt of glyphosate at 2.4kg a.i. ha^{-1} was sequentially applied on March 1 and May 12, 1994 and on March 21 and May 20, 1995. In weedy (untreated) plots, winter weeds were allowed to grow freely over irrigation time. For yield analysis, one sample in 1994 and two samples in 1995 were collected from every replication of both treatments in no-tillage and conventional tillage. Sampling plots at 1m² were established after rice seedlings emerged, because rice seedlings emerged, because rice seedlings in each sampling plot were thinned up to 90 individual seedlings m^{-2}. Besides the samples on the area base, a set of individual rice hills grown in a one meter row was also harvested from each replication of treated and untreated plots. The plant growth and the yield of each rice hill were analyzed to determine the variation in yield components within a population. The number of individual hills per meter was not consistent with the number of emerged rice seedlings (30 per meter) because some individuals within a row joined neighbors and formed a hill.

2. Effect of fertilizer under weedy conditions

In 1995, three different levels of soil fertility were prepared in weedy plots to clarify the effect of fertilizer on the yield reduction from winter weeds. No fertilizer (0×), double dose of fertilizer (2×) and four times higher dose of fertilizer (4×) were separately applied to weedy plots sized at 25m² (5 m× 5 m) via three replications. A sampling plot at 1m² was prepared in each replication in the same way as outlined above. Rice growth and yield were compared with the standard treatment of fertilizer.

Measurements of rice growth at early stage were carried out for five plants collected from every plot on July 4 and 29, 1995. Plant length, leaf stage, tiller number and dry weight were recorded. At the times of harvest in 1994 and 1995, mean plant length and panicle length were estimated using 10 medium-sized hills in each replication. Rice plants in sampling plots at 1m² were reaped with a sickle at about 3cm height above the ground. Yield and yield components were analyzed for each sample of rice plants. After harvest each year, panicle number m^{-2} was counted for every sample, excluding the panicles of weak tillers.

Husked grain m^{-2} was weighed after ripened grains were selected using salty water with specific gravity 1.06. The numbers of ripened grains and unripened grains m^{-2} were separately calculated from the weight m^{-2} and the individual grain weight. The sum of ripened and unripened grain number was recorded as total spikelet number. The mean number of spikelets per panicle was calculated from the total number of spikelets divided by the total number of panicles m^{-2}. Yield was adjusted to 14% moisture content. After rice grains were threshed, the dry weight of the remained straw m^{-2} was recorded. The yield analysis for individual hills was basically the same as above. Winter weeds sampled from 0.25m^2 of each replication at planting time of rice were weighted after they were dried for 7 days in an oven at 70°C.

Results and Discussion

1. Effect of winter weeds on rice yield

Winter weeds in experimental plots consisted of three species, *Alopecurus aequalis* var. *amurensis*, *Poa annua* L., and *Gallium spurium* L. var. *echinospermon* (Wallr.) Hayek. *A. aequalis* var. *amurensis* dominated the experimental field (more than 80% in weight). The sums of dry weight of those weeds at planting time were 694.2gm^{-2} in 1994 and 542.5gm^{-2} in 1995.

Rice growth and yield in 1994 were significantly higher (ab. 400 to 600gm^{-2} in straw weight and ab. 90 to 140gm^{-2} in husked grain weight) than those in 1995 (Table 1). The excellent growth of rice plants in 1994 may be attributed to the scarce cloudy days and very hot weather during the growing season.

Table 1 shows winter weeds in both years reduced plant length (ab. 17cm decrease), panicle length (ab. 1cm decrease) and straw weight (ab. 340 to 430gm^{-2} decrease) of rice plants. Rice plants in weedy plots produced significantly less spikelets m^{-2} (ab. 26,000 to 27,000) than those in the control plots (ab. 33, 000 to 37,000) in both 1994 and 1995. Although the percentages of ripened grain rather increased due to the inhibition of spikelet number by winter weeds, the reduction in spikelet number resulted in 12.6 (1995) to 15.6% (1994) yield reduction compared with the control where a herbicide was treated. However, the yield reduction was statistically significant only in 1994. The ambiguity of the yield reduction in 1995 appeared to be attributed to the lower percentages of ripened grain in 1995 than those in 1994. As described above, there were clear differences in spikelet number m^{-2} between the weedy and control plots in two years. The decreasing rates of the percentages of ripened grain from 1994 to 1995 were similar between those plots (9% decrease in the control and 12% in weedy plots). Under such conditions, the difference in ripened grain number between weedy and the control plots necessarily diminishes in 1995 since their percentages of ripened grain decreased at the similar rate. Thus, the lower percentages of ripened grain in 1995 may have resulted in inconspicuous difference in yield (weight) between weedy and control plots.

The relationships between straw weight and yield components were compared using three samples in 1994 and six samples in 1995, because winter weeds always reduced the plant size, straw weight and spikelet number

Table 1. Comparison of morphology, straw weight and yield traits of rice under different management systems.

System	Plant length (cm)	Panicle length (cm)	No. of panicles /m²	No. of spikelets /panicle	No. of spikelets /m²	% of ripened grain	1,000 grain wt. g	Husked grain wt. g/m²	Grain-straw ratio	Straw wt. g/m²
1994										
No-tillage (control)	99.1 a*	20.4 a	412.5 ab	75.4 a	37,254 a	83.6 b	22.4 b	695.5 a	0.546 b	1534 a
No-tillage (weedy)	82.9 c	19.2 b	393.8 ab	63.5 c	27,271 bc	91.5 a	23.5 a	586.8 b	0.643 b	1190 b
Conventional tillage	89.3 b	20.2 a	470.5 a	61.5 c	34,948 ab	82.8 b	22.5 b	650.8 ab	0.526 b	1471 a
1995										
No-tillage (control)	98.5 a	20.3 a	378.5 b	65.8 bc	33,424 ab	74.7 c	22.2 b	557.5 bc	0.630 b	1103 b
No-tillage (weedy)	81.6 c	18.6 b	345.0 b	61.9 c	26,876 c	79.5 bc	22.7 b	487.3 c	0.903 a	682 c
Conventional tillage	86.6 b	20.5 a	352.0 b	68.4 ab	28,018 bc	85.9 ab	22.5 b	540.9 bc	0.840 a	861 b

* : Values not followed by the same letter differ significantly by Bonferroni's test ($p<0.05$).

of rice (Fig. 1). There was a positive correlation between straw weight and spikelet number m^{-2} in the control plots, while an insignificant relationship was found in weedy plots (Fig. 1-a). Contrarily, rice plants in weedy plots exhibited a positive correlation between straw weight and the percentage of ripened grain (values were transformed by arcsin $\sqrt{\ }$), but an inconspicuous relationship was found in the control plots (Fig. 1-b). There were remarkably positive correlations between straw weight and grain weight in both weedy and the control plots (Fig. 1-c). Rice plants in weedy plots produced higher grain yield than those in the control plots when they produced the same amount of straw, i.e. the rice plants in weedy plots exhibited higher grain-straw ratio than those in the control plots (cf. Table 1). These results indicate that there was a clear difference in the mode of rice yielding between weedy and the control plots, as follows. Rice plants in the control plots increased the number of spikelets as they increased straw weight due to their vigorous growth in the vegetative phase. Those rice plants produced a large amount of yield although their percentages of ripened grain were relatively low. In contrast, winter weeds inhibited the straw production of rice plant, causing a smaller number of spikelets. In weedy plots, the rice plants increased the percentage of ripened grain with the increase of the straw weight, because they had more available resource in their vegetative organs to allocate to a smaller number of spikelets. Thus, rice plants in the weedy and control plots increased the yields in different ways with the increase of the straw weight. The mode of yielding of rice plants under weedy conditions appeared to be similar to that of rice plants grown in low soil fertility[6].

As described above, the high grain-straw ratio of rice plants in weedy plots is considered to be attributed to the high percentage of ripened grain and/or to the low straw weight caused by winter weeds. Winter weeds prevented rice plants from forming large hills, and increased the number of small hills. Rice plants in the control plots tended to join the neighbors forming a small number of large hills. As shown in Fig. 2, the small hills less than 20g in weedy plots tended to be higher in grain-straw ratio than similar small hills in the control plots. The small hills in the control plots did not always bring about the high grain-straw ratio. Thus, the high grain-straw ratio of rice plants in weedy plots appeared to be achieved by their high percentages of ripened grain.

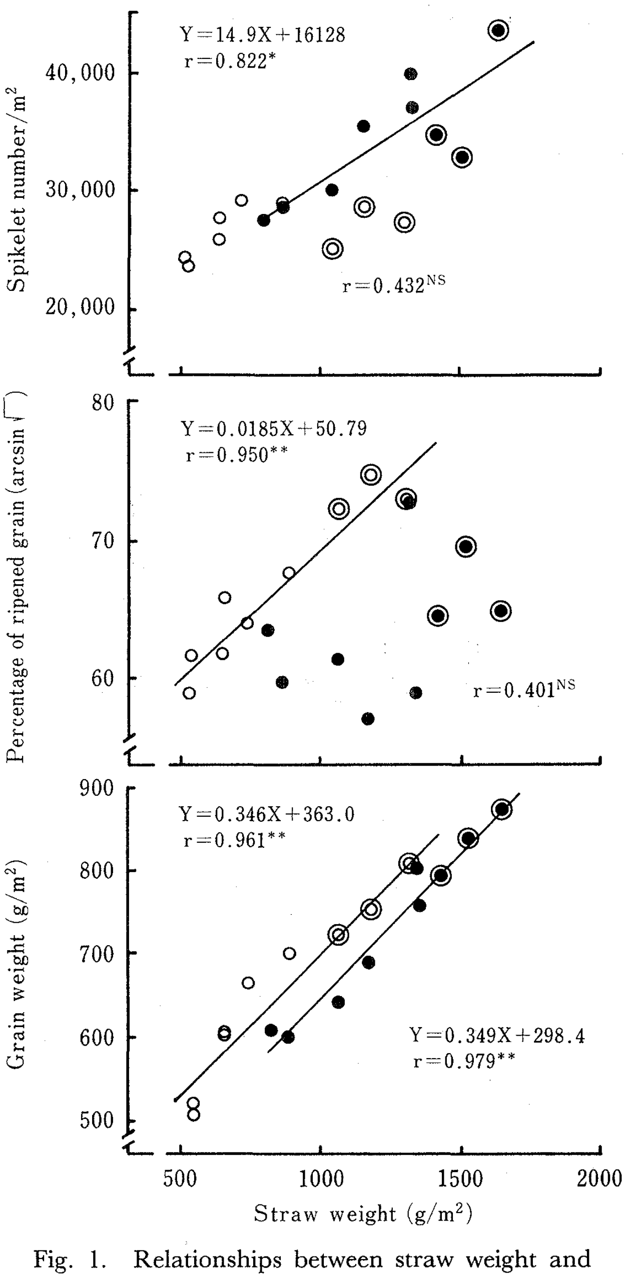

Fig. 1. Relationships between straw weight and spikelet number, percentage of ripened grain or grain weight of rice on area base.
◎ and ○ : Plants of weedy plots in 1994 and 1995, ⦿ and ● : Plants of the control plots in 1994 and 1995.
* and ** : Significant at 0.05 and 0.01 respectively, NS : non-significance.

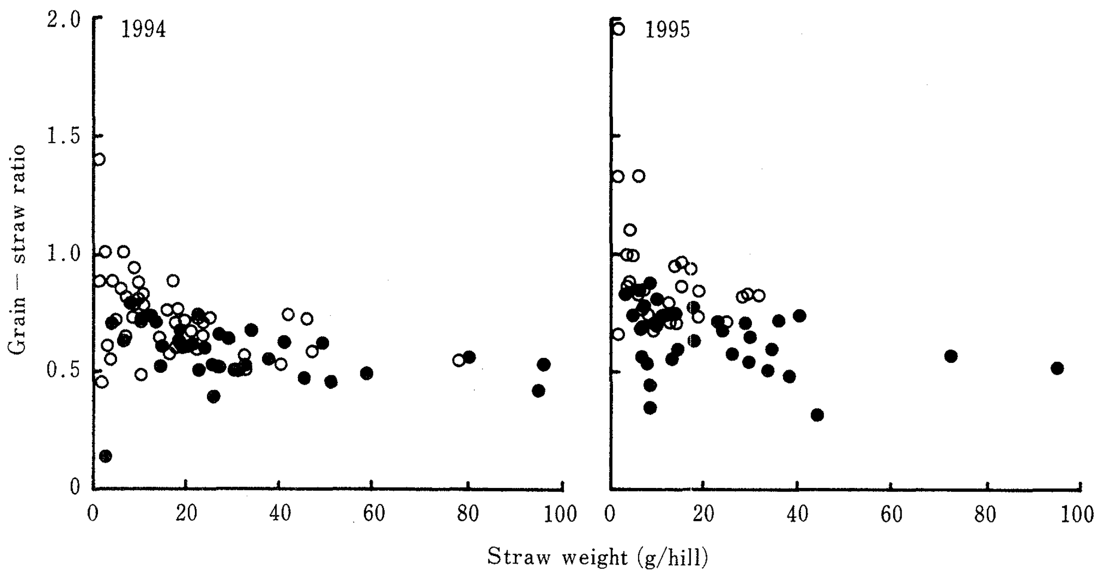

Fig. 2. Scatter diagrams showing grain-straw ratio and straw weight per hill in weedy and control plots.
○ : Hills in weedy plots,
● : Hills in control plots.

2. Effect of fertilizer under weedy conditions

The effect of fertilizer on the interference of winter weeds with rice yield was examined because fertilizer was considered to be a means to recover the damage by winter weeds (Fig. 3). The higher fertilizer treatment (2×) significantly increased the yield and spikelet number of rice in weedy plots as high as those in the control plots. As shown in Table 2, the vegetative growth of rice plant after irrigation was also improved by the high fertilizer treatment, while winter weeds significantly reduced the length of rice plants (ab. 6 and 20cm decrease at 7 and 32 days after irrigation, respectively) and their dry weights (ab. 0.15 and 0.7g decrease). Yet, the highest treatment of fertilizer (4×) did not enhance the yield as high as 2× although the rice plant growth and spikelet number of 4× were highly improved. This was the result of lodging of 4× rice plants after heading.

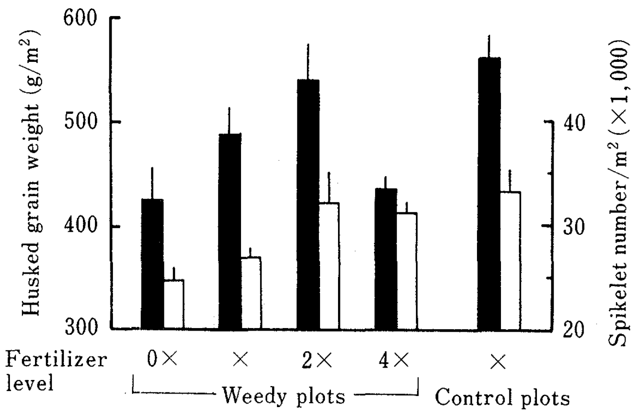

Fig. 3. Response of yield and spikelet number of rice to different fertilizer levels under weedy conditions. ■ : Yield, □ : Spikelet number. Vertical bars indicate mean ± S.E.

Winter weeds are believed to influence both the establishment of rice seedlings and the growth of emerged rice plants. This study showed that unrestrained winter weeds (more than 542gm^{-2}) clearly reduced plant length and dry weight of rice plants from early to harvest stage (cf. Tables 1 and 2), even when rice seedling established quite well under weedy conditions. The heavy trash of the previous rotational crop in no-tillage field also suppressed the growth of rice in the early stage, but the rice plants generally recovered from the damage before the middle of the growth stage[8]. Thus, live weed plants appeared to inhibit the growth of rice more seriously than the trash of rotational crops although they died at the early stage of rice growth. The difference in yield and yield components of rice between the weedy and control plots in this study seemed to be similar to the difference between fertile and unfertile soil conditions[6]. In addition, a higher rate of fertilizer greatly recovered the rice growth and yield in weedy plots. Therefore, the yield reduction by winter weeds appeared to be attributed to the

Table 2. Comparison of the early growth of rice at different soil fertility levels in no-till rice (1995).

Treatment	7 days after irrigation (July 4)*				32 days after irrigation (July 29)		
	Plant length (cm)	Leaf stage	No. of tillers /plant	Dry wt. g /plant	Plant length (cm)	No. of tillers /plant	Dry wt. g /plant
Control plot							
Standard (X)	37.6 a**	6.1 a	2.1 ab	0.30 a	64.4 a	2.3 b	1.44 a
Weedy plot							
No fertilizer (0X)	29.0 b	4.9 b	1.0 b	0.09 b	39.2 c	1.9 b	0.66 b
Standard (X)	31.5 b	5.6 ab	2.0 ab	0.15 b	43.4 c	2.5 b	0.75 b
High fertilizer (2X)	29.2 b	5.0 b	1.7 ab	0.22 ab	48.7 b	5.0 a	1.69 a
High fertilizer (4X)	37.0 a	6.6 a	3.4 a	0.26 a	57.6 a	4.5 a	1.89 a

* : Winter weeds were almost killed on July 4.

** : Values not followed by the same letter differ significantly by Bonferroni's test ($p<0.05$).

low soil fertility. Winter weeds may have reduced the rice yield by taking much of soil fertility before rice plants started growing vigorously.

As described above, the rice growth and yield greatly recovered from the damage by winter weeds with a higher rate of fertilizer. Recently commercialized seeder enables farmers to obtain the good establishment of rice seedlings in weedy fields where *A. aequalis* var. *amurensis* dominates. Thus, the basal dressing of fertilizer at a higher rate possibly reduces the frequency of herbicide application since winter weeds do not always have to be controlled. This may be one of the ways toward labor-saving management in rice cultivation.

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* In Japanese.
** In Japanese with English summary.
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