The influence of weed management on the growth and yield of direct seeded rice (*Oryza sativa* L.)

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Weed management is a primary concern in direct seeded rice (DSR) cropping because weed growth becomes a major constraint on crop yield. A two year field study was set up to evaluate the effect of various weed control measures on crop growth, grain yield and grain quality of DSR. The dry seeded non flooded rice experiment involved five different weed control measures: hand weeding, hoeing, inter-row tine cultivation, inter-row spike hoeing and herbicide treatment (Nominee 100 SC). The extent of weed control (compared to a non-weeded control) ranged from 50-95%. The highest crop yield was obtained using hand weeding. Hand weeding, tine cultivation and herbicide treatment raised the number of fertile rice tillers formed per unit area and the thousand grain weight. Tine cultivation provided an effective and economical level of weed control in the DSR crop.

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Introduction

Rice provides the bulk of food calories consumed by more than half of the world's population. Conventionally grown paddy rice requires a large volume of water and is highly labor intensive; the former is becoming increasingly scarce and the latter increasingly expensive (Saqib *et al*., 2012). Maintaining food security in Asia demands the elaboration of new rice production systems which reduce the crop's requirement for water and avoids the need to perform manual transplanting; one such system is direct seeding into dry soil. Weed growth, which is suppressed in paddy rice by the anoxic soil environment, is a major problem in dryland rice crops. Yield losses incurred when weeds are not controlled can be very high (Chauhan and Johnson, 2011), so deriving workable strategies to suppress weed growth is fast becoming a major research priority (Ladha *et al*., 2007). Manual weeding is an effective means of controlling weeds, but a declining labor force in the rural areas along with the rising cost of labor have encouraged the usage of herbicides (Fischer and Hill, 2004). Selective herbicides are simple to use, can be very efficacious and are not expensive (Pingali *et al*., 1997). However, their continuous use risks the development of genetic resistance, and there are potential downsides to their widespread use associated with their impact on non-farmland vegetation and on human health (Johnson and Mortimer, 2005). The long term sustainability of directly seed rice (DSR) systems requires weed management practices which promote resource conservation and environmental quality (Singh *et al*., 2011). The present study set out to assess the influence of various weed control measures on the productivity and end use quality of a DSR crop.

Material and Methods

A two year field experiment was conducted over the years 2008 to 2009 at the University of Agriculture, Faisalabad, (31º-25‘N, 73º-09‘E). The site's soil is loamy. Meteorological data (Table 1) during the rice seasons of 2008 and 2009 at experimental site the crop followed one of wheat in both years. A tractor-mounted automatic drill, set to an inter-row distance of 22.5 cm and a seeding rate of 75 kg/ha, was used to sow the cultivar Super Basmati at the end of June in each year. Phosphorus (85 P_2O_5 kg/ha) and potassium (67 K_2O kg/ha) were incorporated into the soil prior to planting. Nitrogen (150 kg/ha) was applied in three equal doses of 50 kg/ha at 10, 28 and 50 days after sowing (DAS) in both years. The field was flood-irrigated immediately after sowing and subsequently irrigated as required by the crop. Water was not allowed to stand for more than one day.

The weeding treatments compared were (1) manual weeding, (2) hoeing, (3) weeding between each row with a tine cultivator, (4) weeding between each row using a spike hoe, (5) treatment with Nominee 100 SC (bispyribac sodium) herbicide @ 250 ml ha^{-1}, and (6) a control plot which was not weeded.

Table 1: Local weather data collected during the 2008 and 2009 growing seasons

Month	Rainfall (mm)		Relative Humidity (%)		Temperature (°C)					
					Daily Max.		Daily Min.		Daily Average	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
June	41.7	9.6	48.00	33.6	38.4	40.7	27.4	27.0	32.9	33.8
July	81.6	43.5	52.97	59.0	37.5	38.0	28.3	27.9	32.9	32.9
Aug	204.5	116	65.00	65.8	35.1	36.6	26.8	27.6	30.9	32.1
Sept	28.8	20.6	59.33	61.0	34.4	36.3	23.7	24.4	29.0	30.3
Oct	0	17.5	57.65	57.9	33.1	32.7	20.2	17.1	26.6	24.9
Nov	0	0.7	58.87	64.7	27.3	25.7	12.2	10.8	19.7	18.2

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad

Treatments (1) through (4) were carried out four times, at 15, 25, 35 and 45 DAS, while the herbicide application was given at 15 DAS. Crop was laid down after the implementation of tine cultivator and spike hoe, just like beushening.

Weeds were collected manually from 100 x 100 cm quadrate within each plot at 45 DAS, uprooted, washed with water, separated into sedges and broad leaved weeds, oven-dried at 70°C for 72 h, then weighed. At maturity, the crop was harvested and the number of fertile tillers, the number of grains per panicle, the thousand grain weight and grain yield (at 14% moisture content) were measured. The leaf area index (LAI) was calculated from the ratio of total leaf area to land area according to the expression. The crop's growth rate (CGR) was estimated following Hunt (1978). In both seasons, the experiment was arranged in a randomized complete block design with three replications to allow the data to be analysed by the ANOVA technique. Means differing from one another by one or more $LSD_{0.05}$ were considered to be significantly different (Steel *et al*., 1997).

Results

The various weed management strategies had a significant effect on the accumulation of sedges during both seasons (Fig. 1). In the 2008 season, hand weeding was the most effective method for controlling the growth of sedges (7.28 g/m^2 at 45 DAS), followed by hoeing (31.39 g/m^2), tine cultivation (45.82 g/m^2), herbicide treatment (98.84 g/m^2) and spike hoeing (117.45 g/m^2). In the absence of any control measures, the accumulated dry weight of sedges was 159.46 g/m^2. In the 2009 season, the relative efficacy of the control measures was identical: hand weeding (8.35 g/m^2), hoeing (27.56 g/m^2), tine cultivation (46.65 g/m^2), herbicide treatment (108.50 g/m^2) and spike hoeing (123.56 g/m^2), with an accumulation of 167.56 g/m^2 in the absence of any control measures.

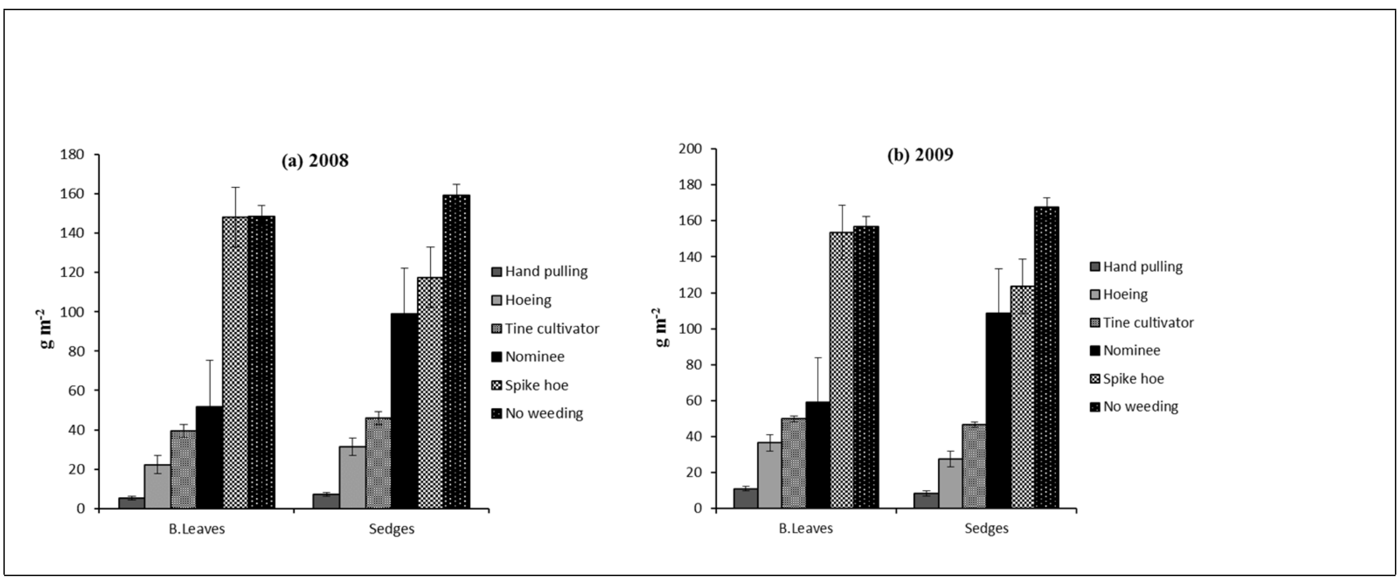

Fig. 1: The effect of the various weed management strategies on the accumulation by 45 DAS of sedges and broad leafed weeds

Similarly the dry weights of broad leafed weeds recorded in the 2008 season were hand weeding (5.1 g/m^2), tine cultivation (39.35 g/m^2), herbicide treatment (51.80 g/m^2), compared with the no weeding control of 148.66 g/m^2; for the 2009 season, the quantities were hand weeding (10.97 g/m^2), tine cultivation (49.87 g/m^2), herbicide treatment (58.91 g/m^2) and no weeding control (156.92 g/m^2) (Fig. 2). Analysis of the crop performance showed that the choice of weed control measure significantly affected the number of fertile tillers formed per m^{-2} (Table 2). During the 2008 season, the hand weeded plots

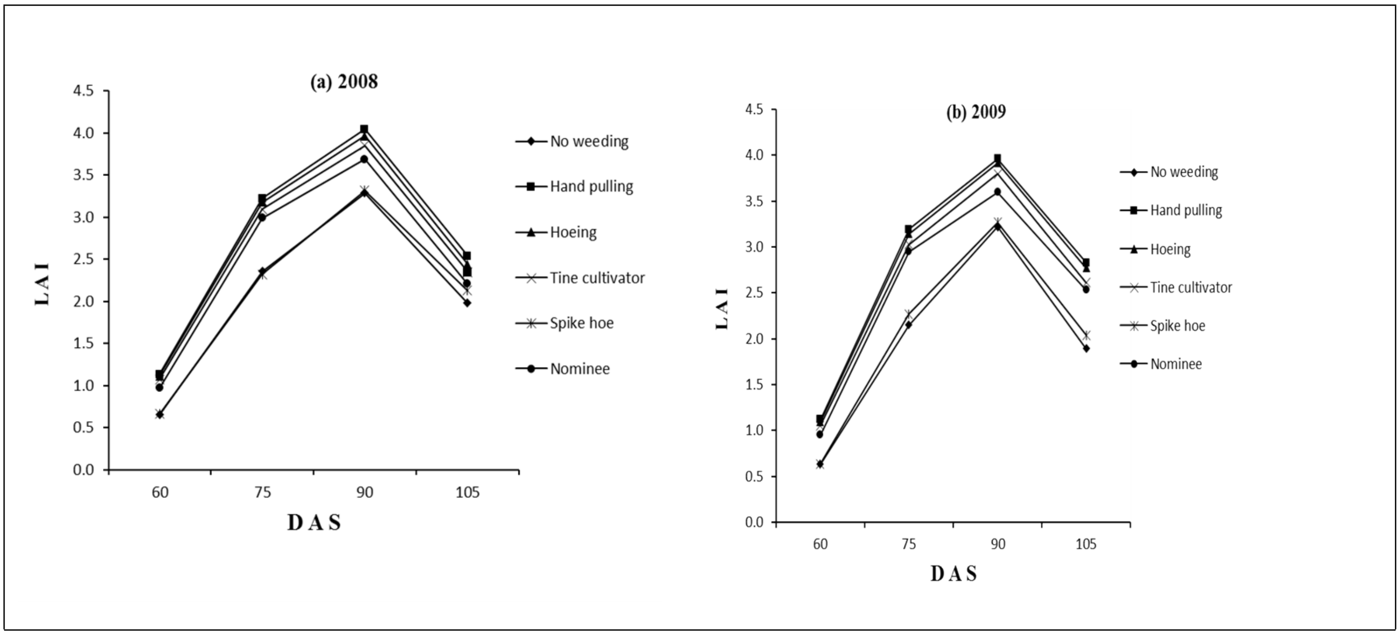

Fig.2: The development of leaf area index in response to the various weed control measures

formed 375.11 fertile tillers per m^2, the tine cultivated plots 350.44 per m^2, the herbicide treated plots 302.92 per m^2 and the spike hoed plots 255.00 per m^2. The unweeded plots only formed 215.58 fertile tillers per m^2. Similarly in the 2009 season, the most productive plots were the hand weeded ones (363.60 fertile tillers per m^2), followed by tine cultivated ones (343.12 per m^2), the herbicide treated ones (283.38 per m^2), the spike hoed ones (243.19 per m^2) and the untreated control plots (181.89 per m^2).

Table 2: The effect of the various weed control measures on crop productivity

Treatments	Productive Tillers(m^{-2})		Kernels Panilcle^{-1}		1000 Grain weight (g)		Grain yield (tha^{-1})		BCR	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
No weeding	215.58 e	181.80 e	60.43 e	59.89 e	14.50 d	15.17 e	1.47 e	1.27 e	0.64	0.61
Hand weeding	375.11 a	363.60 a	78.15 a	76.25 a	20.87 a	20.40 a	4.45 a	4.35 a	1.58	1.72
Hoeing	364.63 a	349.27 b	75.92 a	75.49 a	20.60 a	20.17 a	4.21 a	4.11 a	1.58	1.72
Tine cultivator	350.44 b	343.12 b	74.31 b	73.16 b	19.47 b	19.20 b	3.91 b	3.81 b	1.62	1.75
Nominee	302.92 c	283.38 c	69.43 c	65.97 c	18.07 c	17.60 c	3.02 c	2.59 c	1.26	1.20
Spike hoe	255.00 d	243.19 d	65.50 d	62.89 d	17.17 d	16.52 d	2.44 d	2.05 d	1.02	0.96
LSD	13.80	5.69	1.53	1.02	0.54	0.26	0.29	0.26		

Performance with respect to grain yield of the various plots is presented in Tabe 2, which shows that the choice of weed control measure had a marked effect on this critical trait. In the 2008 season, grain yield was highest in the hand weeded plots (4.45 t/ha), followed by the hoed ones (4.21 t/ha), the tine cultivated ones (3.91 t/ha), the herbicide treated ones (3.02 t/ha) and the spike hoed ones (2.44 t/ha). The yield was very poor when no weeding measures were taken (1.47 t/ha). The 2009 season's outcomes were similar: hand weeding (4.35 t/ha), tine cultivation (3.81 t/ha), herbicide treatment (2.59 t/ha) and control (1.27 t/ha).

The behavior of the leaf area index (LAI) of the crops is shown in Fig. 2. During the 2008 season, the LAI measured at 90 DAS was highest in the hand weeded plots (4.07), followed by the canopy in the hoed plots (3.96), in the tine cultivated ones (3.85), in the herbicide treated ones (3.68), in the spike hoed ones (3.31) and in the no cultivation control (3.28). In the 2009 season, similarly, the hand weeded plots developed the highest LAI (3.96), followed by the hoed plots (3.91), the tine cultivated plots (3.79), the herbicide treated plots (3.59), the spike hoed plots (3.26) and the control (3.21). Crop growth rate (CGR) also responded to the weed control measure applied (Fig. 3). It was highest for the hand weeded plots

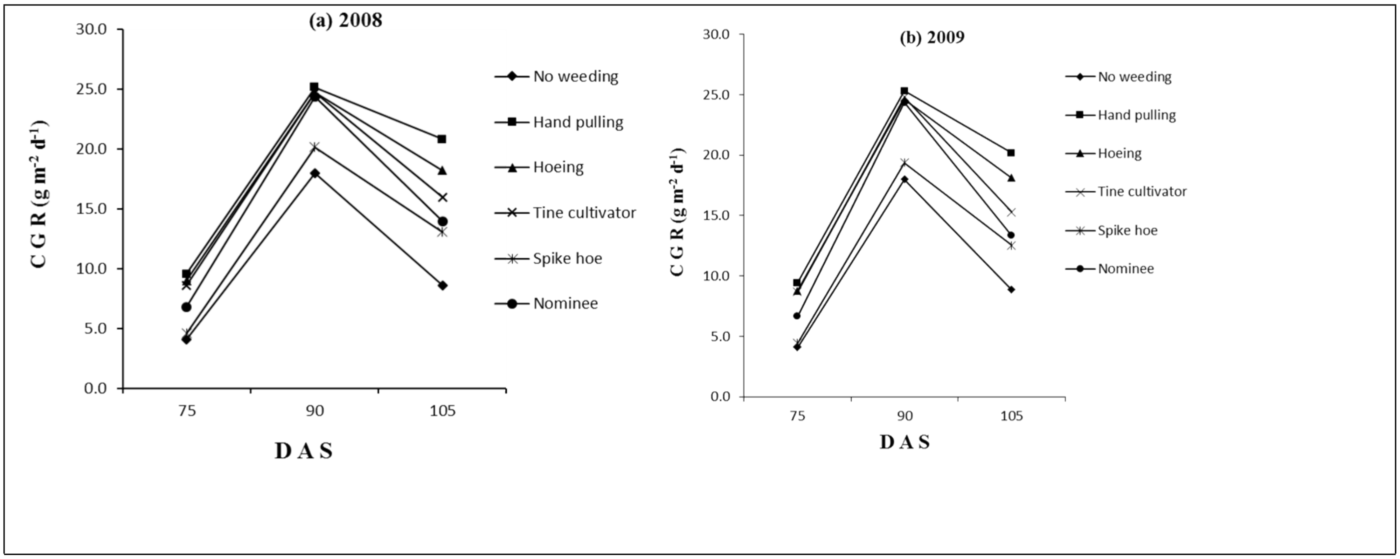

Fig. 3 The development of crop growth rate in response to the various weed control measures

(25.14 g per m² per day), followed by the hoed ones (24.68 g per m² per day), the tine cultivated ones (24.71 g per m² per day), the herbicide treated ones (24.38 g per m² per day), the spike hoed ones (20.14 g per m² per day) and the non-weeded ones (17.95 g per m² per day). Similarly in the 2009 season, CGR varied from 25.30 g per m² per day (hand weeded plots) to 17.99 g per m² per day (non-weeded plots). The highest Benefit cost ratio (BCR) values were noted for the tine cultivated plots (1.62 in 2008, 1.75 in 2009), followed by the hand weeded plots (1.58 and 1.62), the herbicide treated plots (1.26 and 1.20), the spike hoed plots (1.02 and 0.96) and the control plots (0.64 and 0.61).

Grain quality was also affected by the choice of weed control measure (Table 3). In the 2008 harvest, grain protein concentration was highest in the hand weeded plots (7.99%) followed by the tine cultivated ones (7.56%), the herbicide treated ones (7.31%), the spike hoed ones (7.05%) and the non-weeded control ones (6.61%). Similarly, protein concentration in the 2009 harvest varied from 7.96% (hand weeded plots) to 6.54% (non-weeded plots). The amylose concentration of grain from the hand weeded plots was 22.31% in 2008 and 22.23% in 2009, from the hoed plots the proportions were 22.18% and 22.08%, from the tine cultivated plots 21.30% and 21.22%, from the herbicide treated plots 19.27% and

19.16%, from the spike hoed plots 18.95% and 18.84%, and from the non-weeded control plots 18.63% and 18.56%. The grains' water absorption ratios in the 2008 and 2009 harvests were 4.47 and 4.39 (hand weeded plots), 4.33 and 4.24 (hoed plots), 4.08 and 3.94 (tine cultivated plots), 3.68 and 3.57 (herbicide treated plots), 3.33 and 3.22 (spike hoed plots) and 2.94 and 2.86 (control non-weeded plots).

Discussions

Weeds are a major constraint on DSR productivity, having a greater impact on yield than insects, fungi or other pests (Savary *et al.,* 1997). The various weed control measures each had a positive effect on weed biomass accumulation, with four episodes of hand weeding proving to be the most effective method. Hoeing was more effective than spike hoeing, herbicide treatment or tine cultivation. A similar ranking of weed control measures has been noted by Akbar *et al.* (2011). Tine cultivation reduced weed biomass accumulation more than spike hoeing or herbicide treatment did, perhaps because it damaged weeds growing within the rows, thereby delaying their flowering. A second possibility is that the beushaning treatment destroyed all single-stemmed weeds present (Rao *et al*., 2007 and Sharma, 1997). The herbicide treatment was generally less ineffective, perhaps because its active ingredient was an acetol-actate synthase inhibitor.

Table 3 The effect of the various weed control measures on grain quality

Treatments	Kernel protein concentration (%)		Kernel amylose concentration (%)		Kernel water absorption ratio	
	2008	2009	2008	2009	2008	2009
No weeding	6.61 e	6.54 e	18.63 f	18.56 f	2.94 f	2.86 f
Hand weeding	7.99 a	7.96 a	22.31 a	22.23 a	4.47 a	4.39 a
Hoeing	7.96 a	7.93 a	22.18 b	22.08 b	4.33 b	4.24 b
Tine cultivator	7.56 b	7.48 b	21.30 c	21.22 c	4.08 c	3.94 c
Nominee	7.31 c	7.22 c	19.27 d	19.16 d	3.68 d	3.57 d
Spike hoe	7.05 d	6.94 d	18.95 e	18.84 e	3.33 e	3.22 e
LSD	0.15	0.09	0.07	0.10	0.08	0.08

LAI is a useful indicator of crop photosynthetic activity, and responded positively to a reduction in weed pressure. CGR has been used to predict the grain yield of various cereal crops, since reproductive success is highly dependent on plant size (Shipley, 2006). Like LAI, CGR also responded positively to a reduction in weed pressure, presumably because the reduced competition for resources meant that the crop plants were better able to out-compete the weeds (Grotkopp and Rejmanek, 2007). Hand weeding succeeded in increasing the number of fertile tillers formed per unit area by 47%, and this trait generally responded positively to a reduction in weed pressure. Reason might be aerobic soil conditions: emerging DSR seedlings were less competitive with concurrently emerging weeds (Ekleme et al., 2009; Kumar et al., 2008).

The weeding regimes induced significant variation in grain yield in particular, hand weeding and hoeing improved yield over the non-weeded control by, respectively, 70% and 67%. Any reduction in weed pressure can be expected to promote yield as it lessens the strength of the competition for resources between the crop and the weeds (Phoung *et al.,* 2005; Haefele *et al*., 2000). The benefit of tine cultivation was a 64% increase in grain yield, reflecting a good level of control over weeds growing between the rows (Fazlollah *et al*., 2011; Kumar, 2003; Fernandes and Uphoff 2002; Sharma, 1997). The herbicide performed less well, achieving only a 50% benefit over the non-weeded control. Suppressing weeds also promoted grain quality, an important determinant of market price (Singh, 2008; Farooq *et al*., 2011). The improvement in grain amylose and protein concentration achieved by weed control likely reflected a reduced level of weed pressure (Tindal et al. 2005; Rao *et al*., 2007; Singh, 2008; Farooq *et al*., 2011).

Conclusions

Weeds are a major constraint over the yield of DSR. The present study has revealed that hand weeding, hoeing, tine cultivation and herbicide treatment (bispyribac sodium) provided a level of control compared to a non-weeded control of, respectively, 95%, 81%, 71% and 50%. Although hand weeding was the most effective means of control, tine cultivation was more economical, delivering a BCR of 1.75 *vs* 1.72. Weeds can be effectively and economically controlled in DSR using tine cultivation.

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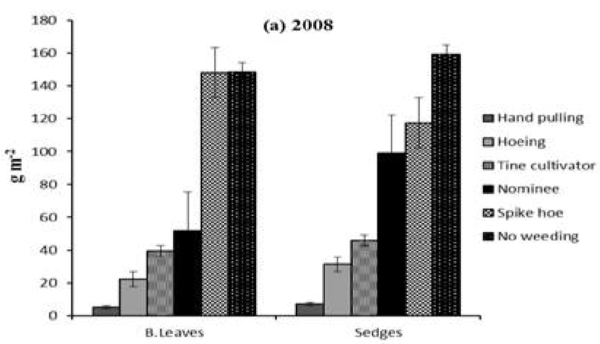
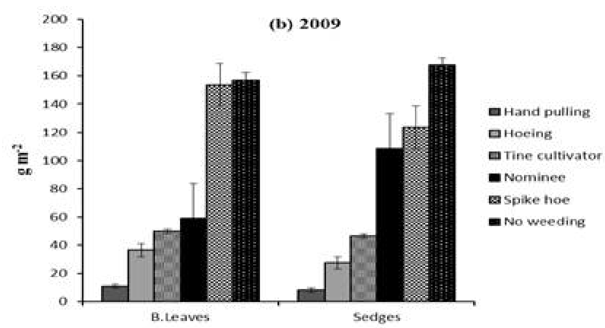
1

The effect of weed management strategies on the accumulation of sedges and broad leaved weeds at 45 DAS





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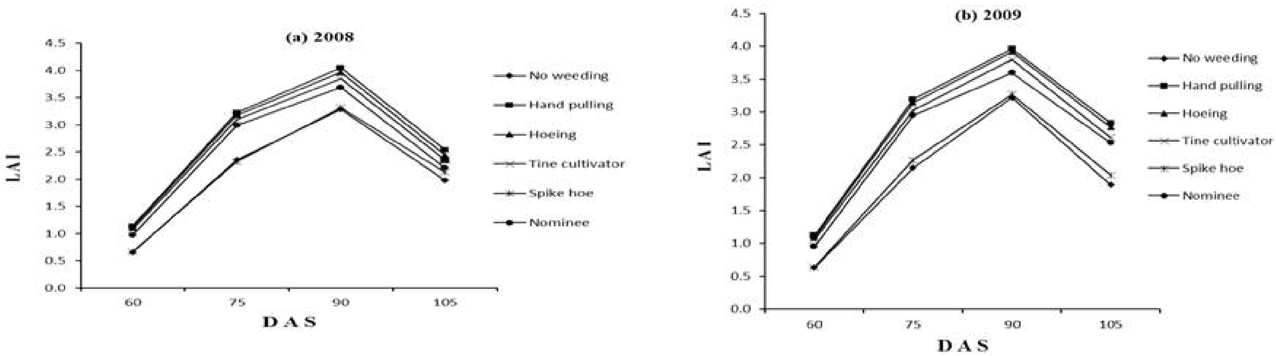
2

Development of leaf area index in response to weed control measures



3

Development of crop growth rate in response to weed control measures