IMPACT OF PLANT POPULATION AND WEED MANAGEMENT PRACTICES ON THE PERFORMANCE OF BASMATI RICE

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DECLARATION

I hereby declare that this thesis entitled **"Impact of plant population and weed management practices on the performance of basmati rice"** is a bonafide record of research work done by me during the course of the research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Impact of plant population and weed management practices on the performance of basmati rice"** is a record of research work done independently by Mr. Jacob. D. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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LIST OF ABBREVATIONS

@	- At the rate of
kg	- Kilogram
g	- Gram
ha	- Hectare
m	- Metre
ai	- Active ingredient
EE	- Ethyl ester
°C	- Degree Celsius
t	- Tonnes
N	- Nitrogen
P	- Phosphorus
K	- Potassium
DAT	- Days after transplanting
DAS	- Days after sowing
NS	- Not significant
Fig.	- Figure
2,4-D	- 2,4 Dichloro phenoxy acetic acid
%	- Per cent
cv.	-Cultivar
cm	-Centimetre

INTRODUCTION

1 INTRODUCTION

Cultivation of basmati rice is increasing every year owing to higher demand in market and higher returns (Chander and Pandey, 2001). Recently rice farmers of Kerala are showing some interest in basmati rice cultivation. For any rice variety, cost of cultivation being the same, basmati rice fetches highest market price and thus provide a better profit to farmer. Geetha *et al* (2000) reported that scented varieties get better premium than nonscented rice varieties in the export market.

Kerala, the home of traditional tall scented rice varieties like Jeerakasala, has recently witnessed the introduction of many high yielding basmati rice varieties like Pusa Basmati-1. These varieties, popularly called as biriyani rice in Kerala, have a local market potential as they are used in preparation of the popular delicacy 'biriyani' (Singh *et al*, 2000b). But specific agrotechniques for the successful cultivation of basmati rice suited to the agroecological situations of Kerala conditions have not yet been standardised.

Among the frontline agronomic packages, optimum plant spacing is of paramount importance to tap the yield potential of rice (Rajarathinam and Balasubramaniyan, 1999). Spacing has a direct influence on the ability of crop to suppress weeds. While wider spacing encourages weed growth, closer spacing has a smothering effect on weeds, as weeds have limited access to sunlight and nutrients.

Weeds are considered as the fourth group of agricultural pests. Competition between weeds and crop plants is mainly for nutrients, water and sunlight (Rao, 2000). The direct and the most important effect of weeds is the reduction in crop yield resulting from the competition for the above factors. Further, weed infestation deteriorates the quality of rice, increases cost of operations such as harvesting, drying and cleaning. Besides harbouring pests and disease organisms, weeds also alter the microclimate making it conducive for out break of pests and diseases.

Data on the comparative estimates of losses caused by weeds, insects and diseases indicate that weeds are more damaging to crops than insect pests and diseases (Bendixen, 1972). Despite this fact, insect pests and plant diseases have drawn greater attention of the farmers and researchers than weeds. This is because injuries caused by insect pests and pathogens to crops are easily noticeable, where as weeds wage a hidden war on the crop plants (Maheswari, 1987).

Losses caused by weeds exceed the losses from any other category of agricultural pests. Of the total annual loss of agricultural produce from various pests in India, weeds account for 45 per cent (Rao, 2000). Extent of yield reduction due to weed infestation ranges from 20 to 62 per cent in rice (AICRIP, 1990). In transplanted rice the same is estimated at 15 to 20 per cent (Singh, 1985) and at 11 per cent (Datta, 1981).

Weed management has always been one of the major expenditure involving operations in rice production, as a good quantum of total labour engaged has been devoted to traditional weeding practices. Hand weeding is an effective method of weed control. Due to exorbitant wage rate combined with low efficiency and non-availability of labour during the peak periods in Kerala, hand weeding has become a burden for cultivators. Moreover, the drudgery in hand weeding necessitated the use of chemicals for economic weed management of rice in Kerala.

In transplanted rice, Japan used 500 man-hours ha^{-1} for control of weeds until 1949, but only 200 man - hours ha^{-1} in 1962, when herbicides were used in conjunction with manual weeding (Yamada, 1966). Use of 500 man-hours ha^{-1} for weeding rice fields accounted for 23.4 per cent of total labour requirement whch reflects the huge expenditure involved in weeding.

As the labour requirement for a single hand weeding range from 300 – 700 man-hours day^{-1} (Ray, 1973), hand weeding becomes most expensive and use of herbicides would result in considerable savings in terms of time, labour, money and other resources for farmers (Sharma *et al.*, 1977).

Since one kilogram of weed growth means a loss of one kilogram of crop growth, development of an appropriate weed management technology using suitable herbicides to the extent needed, in conjunction with cultural management practices is of utmost importance in increasing rice yields. Prevention of weed competition and provision of weed free environment is one of the vital strategies that help sustainable rice production (Sivakumar and Balasubramaniam, 2000).

The weed problem is more acute with high yielding dwarf varieties. The popular cultivated scented variety Pusa Basmati-1, falls in this category. Scented rice varieties are poor competitors of weeds due to their initial slow growth (Chander and Pandey, 2001).

In this context, an investigation was conducted in basmati rice variety Pusa Basmati-1 with the following objectives,

i) To determine the effect of plant population on the growth and yield of basmati rice.

ii) To evolve a suitable and economic weed management strategy for basmati rice.

iii) To find out the effect of herbicide treatment on the weed flora in rice.

iv) To study the nutrient depletion by crop and weeds.

REVIEW OF LITERATURE

2 REVIEW OF LITERATURE

Scented Rice varieties are poor competitors of weeds due to their initial slow growth (Chander and Pandey, 2001). However a perusal of the literature pertaining to the weed management of Pusa Basmati-1 revealed a dearth of information and hence relevant works on other rice varieties are also considered and reviewed hereunder.

2.1 WEED FLORA INFESTING RICE

Weed flora infesting rice crop varies widely with respect to prevailing soil and climatic conditions. Rice fields are colonized by terrestrial, semi aquatic or aquatic plants depending on the type of rice culture and season (Moody and Drost, 1983).

A brief review of weed flora in transplanted rice (Tables 1) suggest that among grassy weeds, *Echinochloa* spp. is the foremost, while *Cyperus* spp. and *Fimbristylis* spp. among the sedges, *Monochoria vaginalis* and *Marsilea quadrifoliata* accounts for the broad leaved group. Also it is seen that even after decades, the weed problem in a particular locality remains more or less the same.

2.2 CROP – WEED COMPETITION

Competition begins when crop and weeds grow in close proximity to one another and when the supply of an essential factor falls below their demands. Weeds are indeed the robbers of all the inputs supplied to the crop and more so the nutrients supplied in the form of fertilizers (Shetty and Krishnamurthy, 1975).

Crop-weed competition is complicated because various factors affect the extent to which it occurs. The total effect of the interference as reflected in crop growth and yield, results from competition for nutrients, moisture and sunlight (Rao, 2000). Stressful levels of environmental factors such as nutrient availability, water, light and temperature influence crop weed interaction, which interfere with weed control and weed control strategies (Patterson, 1995).

Table 1. Weed flora infesting transplanted rice

Location	Grasses	Sedges	Broad leaved	Reference
Vellayani, Kerala	*Echinochloa* spp.	*Cyperus* spp. *Fimbristylis miliaceae*	*Ammania multiflora* *Ludwigia parviflora*	Ravindran (1976)
Vellayani, Kerala	*Echinochloa crus-galli* *Echinochloa colonum* *Brachiaria ramosa*	*Ischaemum rugosum* *Fimbristylis miliaceae* *Cyperus iria*	*Monochoria vaginalis*	Sukumari (1982)
Vellayani, Kerala	*Echinochloa* spp. *Panicum repens* *Brachiaria ramosa*	*Cyperus* spp. *Fimbristylis miliaceae*	*Monochoria vaginalis* *Ludwigia parviflora*	Maheswari (1987)
Pattambi, Kerala	*Echinocloa crus-galli* *Brachiaria* spp.	*Fimbristylis miliaceae*	*Cleome* spp.	Nair and Sadanandan (1975)
Onattukkara, Kerala	*Echinochloa colonum* *Echinochloa crus-galli* *Sacciolepis indica*	*Cyperus iria* *Cyperus rotundus*	*Cleome viscosa* *Monochoria vaginalis*	Lakshmi (1983)
Onattukkara, Kerala	*Echinochloa colonum* *Echinochloa crus-galli* *Brachiaria ramosa* *Cynodon dactylon* *Panicum* spp.	*Cyperus rotundus* *Cyperus iria* *Cyperus difformis* *Scirpus juncoides* *Fimbristylis miliaceae*	*Ammania baccifera* *Ludwigia parviflora* *Marsilea quadrifoliata* *Cleome viscosa* *Monochoria vaginalis* *Leucas aspera.*	Rajan (2000)

Contd…

Table 1 continued

Location	Grasses	Sedges	Broad leaved	Reference
Mannuthy, Kerala	*Cynodon dactylon*	*Cyperus iria* *Cyperus cypermis* *Cyperus difformis*	*Amaranthus viridus* *Ageratum conyzoides,* *Eupatorium odoratum* *Tridax procumbens* *Phyllanthus niruri*	Nair *et al.* (1979)
Mannuthy, Kerala	*Isachne miliaceae* *Sacciolepis interrupta*	*Cyperus iria* *C. difformis*	*Sphenoclea zeylanica,* *Ammannia* spp. *Ludwigia perennis*	Thomas and Sreedevi, (1993)
Haryana	*Echinochloa* spp. *Paspalum distichum*	*Cyperus* spp.	*Eclipta alba*	Dhiman *et al.* (1998)
Madurai, Tamil Nadu,	*Echinochloa colonum*	*Cyperus iria*		Avudaithai and Veerabadran (2000)
Bangalore, Karnataka	*Echinochloa colonum* *Echinochloa crus-galli* *Leptochloa chinensis*	*Cyperus difformis* *Cyperus iria*	*Monochoria vaginalis* *Ludwigia adsandens* *Marsilea quadrifoliata*	Janardhan and Muniyappa (1994)
Indian Agricultural Research Institute, New Delhi	*Echinochloa colonum* *E. crus-galli* *Leptochloa chinensis*		*Eclipta alba* *Commelina benghalensis*	Chander and Pandey (1996)
International Rice Research Institute, Philippines	*Echinochloa crus-galli* *Echinochloa glabrescens*	*Cyperus difformis*	*Monochoria vaginalis*	IRRI (1981)

2.2.1 Critical Period of Competition

Knowledge on the susceptible period of crop life to weed infestation decides the weed management programme to be adopted. Critical period of competition is the period at which the occurrence of weed competition greatly affects the quantity as well as the quality of the crop yield. If the crop is kept weed free during the early stages for a certain length of time, weeds that emerge and develop subsequently may not affect the yield. This intervening period is termed as "critical period" of weed competition (Hewson and Roberts, 1971).

Chang (1970) investigated the effect of weeds emerging at different stages in transplanted rice and concluded that weeds emerging at 15, 30, 45 and 60 days after transplanting reduced the grain yields by 69, 47, 28 and 11 per cent respectively in the first crop. In the second crop, weeds emerging at 10 and 20 days after transplanting reduced the yield by 52.5 and 13 per cent respectively where as weeds which emerged later did not significantly affect crop yield.

Shad and Khan (1988) reported that in transplanted rice cv. Basmati-370, yields significantly declined when weed competition extended beyond 6 weeks or until harvest compared with the unweeded control. Chaudhary *et al.* (1995) observed that mean yield of grain was the highest in the plot kept weed free throughout crop growth period. But this was not significantly different from grain yield obtained from plots kept weed free until 60 days after transplanting. Ali and Sankaran (1984) reported that for higher yields in lowland rice, the crop should be kept free of weeds during the first 50 days in the monsoon and 60 days in summer. However Mukhopadhyay and De (1984) observed the first 25 to 65 days of rice as the critical period.

Shetty and Gill (1974) and Bhan and Mishra (1993) reported that the most critical period of crop-weed competition was between 4 and 6 weeks (28 to 42 days) after transplanting. According to Varughese (1978) and Sukumari (1982), the critical period of crop-weed competition was between 21 and 40 days after transplanting. According to Shasidhar (1983) weed competition was critical during the first 40 days after transplanting paddy and yield reduction was not significant by the presence of weeds there after. Soman (1988) also reported that the weed number and competition was severe up to 40 days after transplanting.

According to Singh (1985), the weeds emerging after the first 25 to 33 per cent of the life cycle of rice plant have less effect on crop yield. Critical period of weed competition in rice was the first one third of the crop growing season (Tjitrosemito, 1993). Thus the critical period of weed competition can be between 20 and 45 days after transplanting rice for a medium duration variety like Pusa Basmai-1 with crop duration of 130 days.

2.2.2 Threshold Level of Competition

Threshold level of competition is the minimum weed density beyond which control measures are necessary. Biswas and Sattar (1993) reported that weed density significantly affected grain yield of rice when 40 or more weeds m^{-2} grew with rice. It was suggested that rice fields should be weeded in the wet season when a weed density of 17 to 42 plants m^{-2} and a weed dry matter yield of 14.1 to 22.3 gm^{-2} is reached, to prevent a 10 per cent reduction in rice grain yield.

2.2.3 Competition for Nutrients

Smith (1968) found out that when water was not limiting, weeds competed with crop thoroughly for nutrients. Chakraborthy (1973) reported that the nitrogen content was significantly higher in weeds than in rice straw. The weeds removed 29.9 and 30.9 kg ha^{-1} of nitrogen in two years and three handweedings brought down nitrogen depletion to 2.66 and 9.88 kg ha^{-1}. He also noticed that the weed species contained much nitrogen at the vegetative, flowering and post flowering stages. Shetty and Gill (1974) pointed out that competition for nutrients between weeds and crop was maximum during the early period of crop growth and competition for soil nitrogen was maximum during 6 to 8 weeks after transplanting. Shetty and Krishnamurthy (1975) found that maximum competition is for nitrogen and weeds were as efficient as rice in taking nitrogen, but rice was far more efficient in absorbing P_2O_5 and K_2O compared to weeds.

. According to Mani (1975), weed growth utilized substantial quantity of nitrogen within 5 to 6 weeks of crop sowing. He also noted comparatively lower amount of nitrogen depletion by weed growth in transplanted rice indicating that puddling operations prior to transplanting effectively checked the weed growth, thus incapacitating its ability to utilize nitrogen from the soil. According to Singh and Sharma (1984), rice direct sown in to puddled soil accumulated more nitrogen during the first 35 days after sowing. But by 75 days after sowing and at harvest, the transplanted rice had accumulated most.

Noda *et al.* (1968) reported that maximum competition for nitrogen between rice and barnyard grass was during the first half of the growing season. Among the rice weeds, *Echinocloa* spp. is the most competitive weeds for nutrients (Sahai and Bhan, 1992). Srinivasan and Palaniappan (1994) found that nutrient removal was greatest under *Marsilea minuta* compared to *Echinochloa* spp.

Weeds remove considerable quantity of nutrients from soil and it is found to be much more than the crop plants. Rethinam and Sankaran (1974) estimated that weeds remove 62.1, 20.0 and 65.3 kg ha^{-1} of N, P_2O_5 and K_2O in rice. Nutrient loss of 86.5 kg N, 12.4 kg P_2O_5 and 134 kg K_2O ha^{-1} due to unchecked weed competition in rice was reported by Chandrakar and Chandrakar (1992).

In transplanted rice, the nutrient depletion by weeds was estimated to be 10.9, 2.6 and 9.8 kg ha^{-1} of N, P_2O_5 and K_2O respectively (Bhan and Mishra, 1993). Balasubramanian (1996) estimated nutrient removal by weeds as 25.10, 6.03 and 20.68 and 30.78, 7.42 and 25.32 kg ha^{-1} of N, P_2O_5 and K_2O at 40 days after transplanting and at harvest respectively. Madhu and Nanjappa (1997) showed that the rate of increase in the uptake of major nutrients by weeds was proportional to the dry matter production of weeds.

Crop-weed competition under high weed intensity exerted some adverse effects on the uptake and utilization of nutrients by crop and weeds to the expected level (Nanjappa and Krishnamurthy, 1980). They also concluded that crop could absorb 109 kg N ha^{-1} in the weed free treatment plots where as the crop and weeds together absorbed only 94 kg N ha^{-1} in unweeded control. Thus some amount of nitrogen remained unabsorbed in the soil. Likewise significant amounts of P_2O_5 and K_2O were left unabsorbed in the soil. Rajan (2000) reported that N, P_2O_5 and K_2O uptake by weeds at harvest were 8.53, 4.18 and 9.26 kg ha^{-1} in unweeded check while it was 56.38, 21.74 and 53.07 kg ha^{-1} by rice crop in the same unweeded check and 142.64, 63.77 and 130.59 kg ha^{-1} in weed free check. But rice crop and weeds together could absorb only 64.91, 25.92 and 62.33 kg N, P_2O_5 and K_2O kg ha^{-1}clearly showing that some amount of nutrients remained unabsorbed in soil due to weed competition.

Correlation studies between depletion of nitrogen by weeds and the grain yield indicated that there was a highly significant negative correlation of (- 0.717 and - 0.674) in the first and second seasons respectively (Rangiah *et al.*, 1975). Okafor and Datta (1976) observed a negative correlation between the total nitrogen uptake by weeds and rice grain yield for all levels of nitrogen applied in all seasons. Ravindran (1976) stated that a negative correlation exists between nitrogen uptake by weeds and nitrogen uptake by crop. Ramamoorthy *et al.* (1974) could obtain strong negative correlation between uptake of nutrients by weeds and grain yield except in the case of phosphorus uptake at 90 days, which was not significant. Varughese (1978) reported negative correlation between nutrient uptake by weed and the crop yield and also nutrient uptake by the crop and weed. He also found that the demand for nutrients was in the decreasing order of K>N>P by crop and weeds.

Mani (1975) opined that the use of herbicides resulted in a substantial decrease in nitrogen depletion by weeds, thus improving the uptake of nitrogen by the crop. Ali and Sankaran (1984) observed increased nitrogen, phosphorus and potassium uptake by rice through weed control. Balaswamy and Kondap (1989) pointed out that nutrient uptake by weeds in transplanted rice, without controlling them up to harvest was 8.98 to 9.25 kg N, 3.50 to 3.81 kg P and 11.05 to 11.81 kg K ha^{-1}. Varshney (1990) observed considerable saving of N, P and K through weed control methods in transplanted rice. From two year study on rice, Nandal and Singh (1993) reported an increase in nutrient uptake of rice by weed control treatments. Chaudhary *et al.* (1995) showed that season long weed free condition resulted in higher accumulation of nitrogen, phosphorus and potassium in rice. Madhu and Nanjappa (1997) showed that the rate of increase in the uptake of nutrients (N, P_2O_5 and K_2O) by rice crop was proportional to the dry matter production. He also pointed out that the total uptake of N, P_2O_5 and K_2O by crop was significantly lower in unweeded check.

Lakshmi (1983) reported that N and K_2O uptake by the crop was higher than P_2O_5 uptake at all stages of growth. According to Vijayaraghavan (1974), in unweeded check, the weeds removed 44.07 kg N, 22.23 kg P_2O_5 and 50.7 kg K_2O ha^{-1} at 90 days which was nearly half the quantity of N, P_2O_5 and two third of K_2O removed by a rice crop yielding 6000 kg ha^{-1}. According to Renjan (1999), at 20 days after transplanting, in unweeded check, weeds removed 7.25, 3.75 and 8.13 kg N, P_2O_5 and K_2O ha^{-1} respectively which is nearly the same quantity of nutrients removed by rice crop in the same plot (6.18, 3.33, 8.52 kg N, P_2O_5 and K_2O ha^{-1}) respectively. Similarly he reported that in the same weedy check, at 40 days after transplanting, weeds removed 23.38, 10.86 and 17.29 kg N, P_2O_5 and K_2O ha^{-1}respectively which is the same quantity of nutrients removed by rice in the same plot (22.59, 9.19, 24.23 kg N, P_2O_5 and K_2O ha^{-1} respectively), thus clearly proving that weeds are as competitive as rice crop during the critical period of crop-weed competition of 20 to 45 days after transplanting.

Under all conditions, it was found that uptake of nutrients by crop was reduced by the presence of weeds and weeds removed more nutrients than the crop. This brief review undoubtedly brings out the fact that weeds are major robbers of plant nutrients. Hence during the present day shortage of fertilizers, the importance of growing rice crop under weed free condition is emphasised.

2.2.4 Competition for Light and Space

Competition for light is one of the most common forms of competition in plant community that occurs whenever one leaf blocks off light from another leaf, either on the same or a different plant. Infact competition for light in field crop may operate through out the crop cycle except when plants are young (Zimdhal, 1980). Modern rice varieties with their upright canopy architecture allow more solar radiation to penetrate through their canopy and encourage increased weed biomass compared to traditional ones with their broad and droopy leaf architecture (Gogoi *et al.*, 2000).

According to King (1966), rate of growth of some weed species enabled them to suppress crop growth and eventually to crowd them out altogether. Smith (1968) reported that barnyard grass shaded rice during the crop season and competition was purely for light when water was not limiting. Gu and Zhao (1984) observed that *Echinochloa* spp: grows faster than rice, competing for light and nutrients and decreasing the crop yield. Srinivasan and Palaniappan (1994) also found *Echinochloa* sp. to be most competitive in reducing the growth and yield of rice and attributed it to lower light transmission ratio under *Echinochloa* sp. compared to other rice weeds. Thus the weeds competing for light and space cause significant yield reduction in rice.

2.2.5 Effect of Crop-Weed Competition on Weed Flora Dynamics

Generally in rice fields, grass weeds occupy a major per cent of total weeds followed by sedges and aquatic weeds (Kumar and Gautam, 1986 and Jayasree, 1987). Verma *et al.*, (1987) reported more number of grassy weeds in association with rice. Chinnusamy (1985) and Venugopal and Kondap (1985) independently observed the dominance of grasses and sedges over broad leaved weeds. Tomer (1991) observed that, of the total weed flora, grasses, sedges and broad leaved weeds in rice accounted to 70, 25 and 5 per cent respectively.

Balasubramanian (1996) noticed that the total weed density under unweeded conditions ranged from 89.6 to 112.8 m^{-2} at 20 days after transplanting, increased to 135.5 to 152.9 m^{-2} at 40 days after transplanting, and remained more or less at the same level at the time of harvest of rice. He also reported that grass weed density increased up to 40 days after transplanting, but declined at maturity while the sedges population increased with advancing growth stage of rice. The density of broad leaved weeds nearly doubled from 20 to 40 days after transplanting and increased further at harvest.

According to Asokaraja (1994) grasses and sedges exerted severe competition during the early period, which caused broad leaved weeds to emerge subsequently coinciding with the cessation of growth of the earlier types. The importance value of grasses was higher than that of sedges and broad leaved weeds (Renjan, 1999).

2.2.6 Effect of Crop-Weed Competition on Rice Growth Characters and Yield Attributes

Weeds exert a direct influence by hindering the growth of rice crop. Ali and Sankaran (1975) noticed that severe infestation of weeds suppressed the height of rice plants. At maturity of rice, the plant height under unweeded check was less by 16.38 to 21.68 cm and dry matter production was reduced by 5.84 to 7.01 t ha^{-1} compared with hand weeding twice (Balasubramanian, 1996).

Renjan (1999) and Nair (2001) reported a decrease in leaf area index due to weed competition in rice. Ramamoorthy *et al.* (1974) found that competition reduced the productive tillers. Balasubramanian (1996) pointed out that productive tillers were only 5 to 7 per hill under unweeded check as against 10.5 to 11.6 per hill with two hand weeding. Muthukrishnan *et al.* (1997) observed that the number of panicles m^{-2} in hand weeded plot was significantly higher than unweeded check, which were 528 and 356 respectively.

While Sukumari (1982) and Lakshmi (1983) reported significant influence of weed growth on the number of filled grains $panicle^{-1}$, Rethinam and Sankaran (1974) observed that weed control treatments had no significant effect on this yield attribute. Weed competition in rice lowered the filled grains $panicle^{-1}$ by 13 per cent and test weight by 4 per cent (Ghobrial, 1981). Arya *et al.* (1991) and Varshney (1991) reported a decrease in thousand grain weight due to weed competition. Reduction in panicle length and thousand grain weight due to weed competition have been reported by Mabbayad and Moody (1992). They also noticed a reduction in tiller number and crop growth rate due to weed competition in rice plants.

Weeds are one of the major causes for low crop yields through out the world. Besides, weeds also reduce crop quality and increase the cost of cultural operations, harvesting, drying, cleaning and cause increased pest and disease infestation.

Shetty and Gill (1974) observed that there was a decline in grain yield of rice by 10 q ha^{-1} when the time of weed removal was extended by 6 to 8 weeks after transplanting. According to Swain *et al.* (1975), when high populations of *Cyperus difformis* competed with rice for the whole of the growing season, rice yields were reduced by 22 to 43 per cent. On an average one *Echinochloa crus-galli* m^{-2} caused a 11 per cent reduction in rice grain yield (Auld and Kim, 1998). Tjitrosemito and Soerianegara (1996) reported that one plant m^{-2} of *Cyperus iria, Ludwigia octovalvis* and *Cyperus difformis* reduced rice grain yield by 62, 49 and 29 kg ha^{-1} respectively. Ravindran (1976) found that the yield reduction caused by weeds in transplanted rice was 28.7 per cent as shown by weed index. Varughese (1978) reported a yield reduction of 25.47 per cent in transplanted rice due to presence of weeds. The extent of yield reduction in rice due to weeds alone was estimated to be around 15 to 20 per cent in transplanted rice, 30 to 35 per cent in direct seeded rice under puddled conditions and over 50 to 60 per cent in upland rice as evident from the data collected over a number of seasons at many locations in India under the multi location testing programme of the All India Co-ordinated Rice Improvement Project (Pillai, 1977).

Moody (1980) reported that yield reduction due to uncontrolled weed growth ranged from 20 to 25 per cent for transplanted rice and 40 to 50 per cent for rice that is broadcast seeded in puddled soil. Singh (1985) reported that in India, the extent of yield reduction in rice due to weeds alone was estimated to be around 15 to 20 per cent in transplanted rice, 30 to 35 per cent in direct seeded rice under puddled situation and over 50 to 60 per cent in upland rice.

Biswas and Sattar (1991) reported that rice uptake of N decreased as weed density increased and this was reflected in decreased yields (13 per cent reduction in yield at 20 weeds m^{-2} and 17 per cent reduction in yield at 40 weeds m^{-2}). According to Kumari and Rao (1993) and Reddy and Gautam (1993), competition stress of weeds exerted reduction in yield of transplanted rice by 50 per cent. Dhiman and Nandal (1995) estimated a yield reduction of 23.71 per cent in transplanted rice. Weedy control until maturity reduced the grain yield by 49 per cent in transplanted rice compared to weed free up to 60 DAT (Singh *et al.*, 1999). Nandal *et al.* (1999) showed that in transplanted rice, the average reduction in rice grain yield was 43.2 per cent in an unweeded control compared to the weed free treatment.

According to Renjan (1999), yield reduction due to weeds in transplanted rice is 44.94 per cent. He also reported that grain and straw yield were positively correlated with plant height, leaf area index, total dry matter production at harvest, productive tillers, panicle weight, thousand grain weight and nutrient uptake by the crop and negatively correlated with weed count, weed dry matter production and nutrient removal by weeds. Rao and Singh (1997) also reported negative correlation between grain yield and weed dry weight. Thus the above review indicates the severity of damage caused by weeds in rice fields.

2.3 EFFECT OF SPACING

2.3.1 Effect of Spacing on Weed Flora

In recent years, attempts have been made to introduce weed-competitive cultivars of rice. In transplanted rice, use of competitive cultivars in conjunction with higher seed rates and shallow submergence has reduced weed competition. In lowland transplanted rice, closer spacing and application of herbicides resulted in fewer weeds (Gogoi, 1998). He also opined that growing rice at closer spacing decreased weed numbers. Ghosh and Singh (1996) proved that reduction of plant density enhanced weed infestation. Ghosh and Sarkar (1975) had shown that as the distance between hills of transplanted rice is reduced the crop became more competitive and weed population was reduced. The yield of semi dwarf cultivars can be increased and weed competing ability improved by decreasing the spacing from 25 x 25 cm to 15 x 15 cm (IRRI, 1976).

Estornios and Moody (1983) found that under identical management practices, weed dry weight and yield were lowest at closer spacing. Transplanting of seedlings at 44.4 hills m^{-2} significantly decreased the density and dry weight of weeds and significantly increased the paddy yield compared to 26.66 hills per m^{-2} (Verma *et al.*, 1988). In their studies, rice grown at a spacing of 44 and 27 plants m^{-2} gave two year average paddy yields of 5.38 and 4.61tha^{-1}.

Singh *et al.* (1999) reported that among the three spacings tried (10 x 10 cm, 15 x 10 cm and 20 x 10 cm), the weed population increased significantly with increase in spacing. They also opined that weed control efficiency increased from 61.6 per cent in 20 x 10 cm spacing to 66.4 per cent in 10 x 10 cm spacing. Thus weed control efficiency increased as spacing decreased. Lourduraj *et al.* (2000) found that weed count and weed dry weight were higher under wider planting of 33 hills m^{-2} (20 x 15 cm) compared to closer planting of 50 hills m^{-2} (20 x 10 cm).

Relative weed density of each species increased with increase in spacing from 20 x 10 cm to 30.x 20 cm (Khondaker and Sato, 1996). He further pointed out that weed growth increased significantly with increase in spacing and weed growth rate was higher at 25 DAT than at 45 DAT.

Barnyard grass produced more tillers at lower rice density (Guo and Yong, 2001). They also reported that when the rice density was increased, the growth rate and leaf area index of barnyard grass decreased. Yong and Seiji (2000) indicated that high rice density is favourable for competing with barnyard grass in paddy fields.

Lourduraj *et al.* (2000) explained that weed count and weed dry weight were higher under lower planting density of 33 hills m^{-2} compared to 50 hills m^{-2}. This is due to larger land area between two rice hills under wider planting density which facilitated weed emergence and growth. In the case of closer planting, rice seedlings would have exercised a smothering effect reducing weed number and dry weight.

2.3.2 Effect of Spacing on Yield

The yield potential is not fully exploited if population is inadequate. Plant density plays an important role in yield maximization of rice (Paraye *et al.*, 1996; Patel, 1999; Siddiqui *et al.*, 1999). Fu *et al.* (2000) had reported that decreasing the plant spacing significantly decreased plant height. He also opined that with a decrease in plant density, the number of tillers and leaves increased and the growth period was extended.

Considerable volume of scientific data is available to show that the spacing adopted has a significant impact on yield. Hua *et al.* (2000) reported that light penetration of the canopy decreased along with decrease in plant spacing. Lourduraj (1999) reported that planting geometry has pronounced effect on tillering and interception and utilization of light in rice. He also opined that for low tillering rice cultivars, yield declined as plant spacing increased from 15 x 15 cm to 25 x 25 cm, while high tillering cultivars showed the opposite trend. He further pointed out that for medium duration rice cultivars, the optimum plant population for achieving maximum yield is 50 hills m^{-2} (20 x 10 cm). Increasing the population to 80 hills m^{-2} reduced the grain yield considerably.

Patel (1999) observed that grain yields decreased when spacing was increased from 20 x 10 to 20 x 20 cm. Shrirame *et al.* (2000) reported that with decreasing plant density, there was increase in number of functional leaves per hill, maximum leaf area per hill and total number of tillers per hill. Crusciol *et al.* (2000) obtained more number of stalks and panicles per unit area with decreasing row spacing resulting in a higher yield. Kyeong *et al.* (1999) suggested that in transplanted rice, eventhough the number of panicles per hectare increased with increasing plant density, the number of grains per panicle decreased.

In humid tropic environment, high plant density of rice resulted in excessive vegetative growth. The resulting inter and intra plant competition and low radiation during anthesis and grain filling caused high rate (40 to 70 per cent) of tiller abortion, delay in flowering of late tillers, low percentage of filled spikelets and low yield despite a high biomass production (Tuong *et al.*, 2000).

Saha (1998) reported that the number of high density grain (HDG) in the upper portions of rice panicles decreased with increased plant population. He also pointed out that number of HDG and grain yield were significantly correlated and that wider spacing gave better grain filling due to lesser competition among the plants for light, space, water and nutrition.

Regression analysis indicated that seedlings m^{-2} is an important factor contributing much to grain yield in transplanted rice compared to seedling dry weight (Sharma and Ghosh, 1999). Satyavathi *et al.* (2001) reported positive and significant correlation for yield per plant with the number of productive tillers per plant at 20 x 10 cm spacing. They also reported that number of productive tillers per plant, number of grains per panicle, and hundred rice grain weight had maximum direct positive effect on grain yield per plant where as spikelet sterility at different spacing revealed a negative direct effect on yield.

Anbumani *et al.* (1999) pointed out that for sustainable rice based cropping system, transplanting of ADT 38 in rows with a spacing of 20 x 10 cm is the best. Rajarathinam and Balasubramaniyan (1999) compared different plant populations of 50, 33 and 25 hills m^{-2} using rice hybrid CORH2 and concluded that yield parameters namely panicles m^{-2}, panicle weight and length, grains per panicle, filled grains per panicle, harvest index, thousand grain weight and grain yield were highest with the population of 50 hills m^{-2}.

Geethadevi *et al.* (2000) reported that maximum grain yield of hybrid rice was obtained with wider spacing of 20 x 10 cm, than with 15 x 10 cm. They also reported significant positive correlations between grain yield and spikelet number per panicle, panicle length, grain weight per hill, thousand grain weight and weight per panicle. Wider spacing increased the extent of the root system and resulted in higher grain yield per plant compared to closer spacing (Kujira, 1990). According to Bindra and Kalia (2000), increasing the normal plant stand of 20 x 10 cm by 33 per cent could not exhibit positive effect on grain yield. Singh *et al.* (1998) reported that nutrient (N, P and K) depletion by weeds in rice decreased with a reduction in spacing. Rajarathinam and Balasubramaniyan (1999) found that dry matter production, straw yield, nitrogen uptake and content of rice increased with increasing number of hills m^{-2} from 25 to 50 hills m^{-2}.

Padmajarao (1995) studied grain yield of scented rice cv. Basmati 370 transplanted at 20 x 20, 20 x 15 or 20 x 10 cm spacings and reported that closest plant spacing resulted in highest yield and higher number of high density grains. Om *et al.* (1993) observed that transplanting Basmati 370 at 15, 22.5 or 30 x 15 cm produced grain yields of 4.08, 3.91 and 3.63 t respectively.

While comparing grain yields from scented rice cv. Haryana Basmati-1 planted at 15 x 15 or 20 x 15 cm spacing, grain yield remained unaffected by spacings (Dhiman *et al.*, 1995). In scented rice cv. Kasturi, seedlings transplanted at 15 or 20 x 15 cm failed to affect grain yield significantly (Singh and Pillai, 1995).

The influence of plant density on scented rice cv. Basmati 385 was reported by Karim *et al.* (1992). They observed that thousand grain weight, cooked grain length, total milling recovery and head rice recovery decreased with increasing plant density. Gel length and amylose concentration increased at the highest density while protein concentration tented to decrease as plant density increased. In a field experiment on Basmati 385 grown at spacings of 30 x 25, 20, 16 or 10 cm or 20 x 20 cm, the 20 x 20 cm spacing produced the highest grain yield of 4.88 t ha^{-1} (Rafiq *et al.*, 1998).

Patra and Nayak (2001) explained that the superior grain yield under closer spacing compared to wider spacing is mainly due to the higher panicles m^{-2} at closer spacing. They also observed that effective tillers $hill^{-1}$ increased significantly with wider spacing while closer spacing of 10 x 10 cm recorded significantly lower number of grains per panicle. Zadeh and Mirlohi (1998) gave a similar explanation. According to them, closer spacing resulted in increased number of tillers and panicles per unit area but tillers per plant and number of grains per panicle decreased. At wider spacing, grain yield per unit area decreased although grain yield per plant and harvest index increased. They opined that the number of panicles per unit area is the most important component determining grain yield. But the indirect effect of panicle number per unit area on yield through its association with grain number per panicle prevented grain number per panicle from having a significant impact on yield.

2.4 WEED CONTROL IN TRANSPLANTED RICE

One of the best guides for choosing appropriate method of weed control is the relative cost of labour and herbicides. Selection of an appropriate method of weed control technology should be based not on the degree of weed control or the cost of weed control alone. All these factors should be considered in deciding the weed control method that provides the highest returns per unit invested.

Reliance on a single method of weed control such as continuous use of the same or similar herbicides could create serious problem by perennial weeds and may also result in weed shift. So recent approach in weed control is the development of integrated method of weed control using a combination of low cost chemicals along with hand weeding technique which may be the most effective alternative from agronomic, economic and ecological point of view.

2.4.1 Physical Weed Control by Hand Weeding

According to Crafts and Robbin (1973), hand pulling of weeds was an efficient method of eliminating annual and biennial weeds, which do not recover again. Rangiah *et al.* (1975) reported that hand weeding and working rotary weeder recorded maximum yields and net profit and also effectively controlled the weeds. Handweeding resulted in higher grain yield of rice (Azad *et al.* 1990; Singh *et al.*, 1992; and Singh *et al.*, 1994).

Khare and Jain (1995) found that hand weeding gave the lowest weed biomass and highest weed control efficiency (60 kg ha^{-1} and 91.6 per cent, respectively). Chandrakar and Chandrawanshi (1985) pointed out that the hand weeded plots recorded the highest number of panicles m^{-2}, highest grain yield and the least dry weight of weeds. Preliminary evaluation of weed control practices in transplanted rice revealed that yield increase due to hand weeding in the farmer's fields ranged from 4 to 29 per cent (Elliot *et al.*, 1985). Moody (1980) observed that the effect of hand weeding given to the first crop of rice was found to be carried over to the second crop.

Yang *et al.* (1980) found that plant height and number of culms per hill were a little higher in herbicide treatments than in hand weeded plots in the first year, but decreased slightly with each successive year of herbicide application. Hand weeding is effective and is the most common tool to control weeds in transplanted rice (Muthukrishnan *et al.*, 1997). Balasubramanian (1996) pointed out that number of productive tillers in rice was enhanced by hand weeding twice. Patel and Metha (1986) indicated highest reduction in weed biomass with soil solarisation and hand weeding. The reduction in weed dry weight due to hand weeding was 88 per cent (Raju and Reddy, 1986). Hand weeding twice registered a high weed control index of 81.9 per cent (Kathiresan and Surendran, 1992).

Moody (1980) suggested that in transplanted rice, one manual weeding (at the most two) was sufficient to control weeds adequately. He also found that manual weeding methods are most effective on young weeds. Several literature points out the superiority of hand weeding thrice over hand weeding twice in scented rice varieties like basmati. Ahmed (1978) reported that rice cv. IR-8 gave maximum yields when hand weeded twice at 20 and 35 or at 20 and 40 days after transplanting while cv. Basmati gave highest yield with three hand weedings, but in both cultivars, maximum benefit-cost ratio was obtained with one hand weeding at 20 days after planting.

Chander and Pandey (1996) reported that manual weeding thrice is superior to butachlor at 1.0 kg ha^{-1}, chlorimuron ethyl at 0.012 kg ha^{-1} or anilofos at 0.5 kg ha^{-1} as it resulted in the maximum decrease in weed population and dry weight and a corresponding maximum increase in yield of scented rice cv. Pusa Basmati-1. They found that nutrient uptake of crop was highest at 30, 45 and 60 days after transplanting (88-104 kg N, 11-16 kg P_2O_5 and 146-172 kg K_2O ha^{-1}) in herbicide treated plots and lowest in unweeded plots (42 to 54 kg N, 5 to 8 kg P_2O_5 and 79 to 84 kg K_2O ha^{-1}). The highest depletion of N, P and K by weeds was in unweeded plots (42.7 kg N, 4.5 kg P_2O_5 and 63.1 kg K_2O ha^{-1}) and the lowest in hand weeded plots (5.3 kg N, 0.6 kg P_2O_5 and 7.7 kg K_2O ha^{-1}).

Gupta *et al.* (1975) found that the local practice of hand weeding thrice was inferior to herbicide treatments like C 19490 (Piperophos) and Machete G (Butachlor) and he attributed this to the subsequent recuperation of weeds after hand weeding and also the damage done to the crop during the early stages of crop growth. According to Mukhopadhyay (1967), the cultural methods of controlling weeds namely, hand weeding and wheel hoeing were comparatively less effective than chemical or chemical plus cultural method of weeding, in reducing weed or increasing the yield of rice. Verma *et al.*, (1987) found that hand weeding could not stop re-emergence of sedges. Mechanical or manual weeding is difficult many a times due to continuous rains prevailing during rainy season and also due to scanty labour (Gogoi *et al*, 2000).

The manual method of weed control is laborious, back breaking and time consuming (Mani and Gautam, 1973). Rao (2000) opined that manual weeding is effective against annuals and biennials but do not control perennials and is expensive in areas where labour is scarce. Ravindran (1976) reported that hand weeding on the 20^{th} and 40^{th} day after transplanting rice, although gave higher yields, the net profit was lower due to increased labour charges. Singh and Sharma (1984) reported that hand weeding provided fairly good control of weeds because weeds from both inter and intra rows are removed, but it was laborious and expensive. The cost-benefit ratio showed a negative return from hand weeding mainly due to very high labour cost. Thus it is seen that the traditional method of hand weeding continued to exhibit good weed control and record better yield. Where labour is cheap and plentiful, this method can be followed. For small holdings, use of traditional methods of weed control continues to be the most economical method.

2.4.2 Chemical Weed Control

Though hand weeding is the common practice of weed control in rice, due to increased cost and non-availability of labour at the optimum weeding time, the situation has changed, necessitating the use of chemicals. Use of pre emergence herbicides like anilofos, reduce the crop-weed competition during the initial crucial stages of growth. Prasad *et al.* (1992) reported that use of herbicides could save up to 75 per cent energy input in weed management and gave 20 per cent more energy output than hand weeding. He also reported that energy use efficiency was higher with herbicides than with hand weeding. Chemical measures though effective and economical in upland ecosystem, their efficiencies are greatly reduced in puddled rice due to inundation and runoff losses. So integrated weed management involving both chemical and other agronomic manipulation may offer effective and economical weed control in puddled rice (Gogoi *et al.*, 2001).

2.4.2.1 Anilofos

Anilofos is one of the recent additions to the list of rice herbicides used in India. It has pre-emergence and early post emergence activity. In transplanted crop, it can be applied between 4 to10 DAT at 0.4 kg ai ha^{-1} (Thomas and Abraham, 1998).

Numerous literature points to the superiority of anilofos over the standard rice herbicide butachlor as can be seen from the following reports. Evaluation of herbicides for transplanted rice in Kerala by Joy *et al.* (1991) on rice cv. MO-6 found anilofos 0.6 kg ha^{-1} as effective and more economic than hand weeding. In a study conducted to ascertain the influence of different pre-emergence herbicides on weed control and crop performance in transplanted rice, Balaswamy (1999) found out that anilofos gave a higher weed control efficiency of 84.32 per cent.

Based on field trials on scented rice variety Pusa Basmati-1, Singh and Kumar (1999) reported that the grain yield of 3.86 t ha^{-1} from plots applied with anilofos at 0.6 kg ha^{-1} was second only to plots hand weeded twice (3.87 t ha^{-1}). While plots subjected to sequential application of anilofos at 0.6 kg ha^{-1}, registered a higher yield of 3.86 t ha^{-1}, plots treated with the standard rice herbicide butachlor at 1.5 kg ha^{-1} recorded only a lower yield of 3.69 t ha^{-1}.

Khare and Jain (1995) ranked the performance of weed control chemicals in transplanted rice in descending order as anilofos> thiobencarb>butachlor.

Some literature on anilofos goes to the extent of crediting Anilophos for control of broad leaved weeds and sedges too apart from grassy weeds. According to Munegowda *et al.* (1990), anilofos at 0.6 kg ha^{-1} applied at 4, 7 or 10 DAT gave excellent control of grass weeds, including some broad leaved species at 30 and 60 DAT. Sedges and grasses were effectively controlled with anilofos resulting in a higher weed control efficiency of 84.32 per cent (Balaswamy, 1999).

Where the standard rice herbicide butachlor failed, anilofos came to the rescue thus prompting many scientists to compare performance of anilofos with new generation herbicides like piperophos, cinmethylin and chlorimuron-ethyl and combination herbicides involving 2,4-D. According to Singh *et al.* (1990), butachlor at 1.5 kg ha^{-1} gave only partial control of weed *Ischaemum rugosum* while anilofos at both 0.4 and 0.5 kg ha^{-1} controlled this weed effectively and thus resulted in significantly higher yields than were obtained from plots treated with Butachlor at 1.5 kg ha^{-1} or with two hand weedings at 21 and 35 DAT. Increasing the application rate of butachlor from 1.5 to 2.0 kg ha^{-1} did control this weed but resulted in toxicity to the crop during the early growth stage from which the crop recovered.

Chander and Pandey (1996) based on herbicide studies on scented rice cv. Pusa Basmati-1 found that anilofos at 0.5 kg ha^{-1} gave the best over all weed control and highest grain yield compared to butachlor at 1.0 kg ha^{-1} and chlorimuron ethyl at 0.012 kg ha^{-1}. Chlorimuron ethyl was found to be most effective against broad leaved weeds. Field trials by Brar *et al.* (1997) to assess the efficacy of cinmethylin compared to anilofos at 0.3 kg ha^{-1}applied at 3 DAT showed that cinmethylin 0.08 to 0.10 kg ha^{-1} applied at 10 DAT or earlier resulted in best weed control which is comparable to those achieved with anilofos.

Krishnasamy *et al.* (1993), based on trials conducted in Tamil Nadu, found anilofos at 0.4 kg ha^{-1}on par with piperophos (1.0 kg ha^{-1}) and superior to both butachlor (1.5 kg ha^{-1}) and EPTC+2,4-D (1.0 + 0.5 kg ha^{-1}) in controlling *Echinochloa crus-galli* and other rice weeds and also resulted in highest grain yields. Gogoi *et al.* (2000) found anilofos 0.4 kg ha^{-1} and butachlor + 2,4-D mixture (1.0 kg ha^{-1}) in 60:40 proportion to be equally effective in controlling weeds and increasing rice yields in transplanted rice. Balaswamy and Kondap (1989) also found that in transplanted rice, anilofos and fluchloralin+2,4-D EE were equally effective in decreasing nutrient uptake by weeds and increasing N, P, and K uptake by rice.

Some literature on anilofos pertains to arriving at the optimum time and dose of the herbicide for weed management in rice. According to Munegowda *et al.* (1990), there is no significant difference in grain yields obtained from anilofos at 0.4 kg and 0.6 kg ha^{-1}. But the higher rate proved to be more effective in controlling weeds. He further pointed out that anilofos at 0.6 kg ha^{-1} applied at 10 DAT resulted in some leaf curl and discolouration in the test crop rice cv. Prakash, but phytotoxicity disappeared with increasing age of the crop and no phytotoxicity was seen in freshly emerged leaves. Gill *et al.* (1991), based on trials at Ludhiana, compared anilofos 0.3 to 0.5 kg ha^{-1} applied at 7 DAT and found that anilofos at 0.5 kg ha^{-1} resulted in the lowest weed dry weight and effective control of weeds *Echinochloa crus-galli* and *Ischaemum rugosum*. But the highest rice grain yield was from plots treated with anilofos at 0.3 kg ha^{-1}.

Jain *et al.* (1998) reported that in rice at 60 DAT, anilofos at a higher dose of 0.6 kg ha^{-1} is superior to a lower dose of 0.4 kg ha^{-1}, as it resulted in greatest weed control efficiency of 91.54 per cent, maximum grain yield and lowest energy utilization by weeds (91.41 lakh kcal ha^{-1}). Both doses of anilofos resulted in higher energy utilization by rice. Ravi *et al.* (2000) evaluated different doses of the herbicide (0.40, 0.45, 0.50, 0.55, 0.60 kg ai ha^{-1}) in controlling weeds in transplanted rice cv. ADT 36 at Pattukkottai, Tamil Nadu and concluded that the minimum weed population and maximum rice grain yield were noticed in plots treated with anilofos at 0.6 kg ai ha^{-1} and the crop growth was comparable with the weed-free control.

Based on trials with 0.30 to 0.45 kg ai ha^{-1} anilofos applied at 3 or 6 DAT on rice cv. IR 50 at Karnataka, Kumar and Basavaraj (1996) concluded that anilofos applied at 6 DAT produced grain yield which was not significantly different from yield obtained from weed free plot. Nandal and Singh (1994) reported that for transplanted rice, anilofos 0.45 kg ha^{-1} and 0.60 kg ha^{-1} applied 5 or 10 DAT were equally effective in suppressing weed growth and resulted in higher grain yield of rice.

2.4.2.2 Anilofos Followed by Hand Weeding

Pre emergence application of anilofos at 0.4 kg ha^{-1} supplemented with one hand weeding at 40 DAT resulted in significantly higher grain yield (yield reduction was only 4 per cent compared to weed free up to 60 DAT), net income and benefit-cost ratio and nitrogen uptake. It also resulted in the minimum weed density and dry weight among chemical treatments (Singh *et al.*, 1999). Singh and Kumar (1999) reported highest cost-benefit ratio of 1.96 from a single application of anilofos followed by one hand weeding in scented rice cv. Pusa Basmati-1.

2.4.2.3 2,4-dichlorophenoxy acetic acid (2,4-D)

For the past four or five decades, weed control in rice centered around the chlorophenoxy herbicide, 2,4-D. Many rice growers have been using it routinely for the control of annual broad leaved weeds such as *Monochoria vaginalis*, *Sphenoclea zeylanica*, Sedges such as *Cyperus difformis*, *Cyperus iria* and *Fimbristylis littoralis* (Datta, 1981). Most dicotyledonous crops are sensitive to 2,4-D (Rao, 2000).

2,4-D formulations are either esters emulsified in oil (EE) or water soluble salts such as sodium. Of these, 2,4-D sodium salt is the most widely used formulation in rice farming. Ester formulations (EE) are more toxic to weeds and less selective than salt formulations. 2,4-D sodium salt is recommended for application at 20-25 DAT at 0.8 to 1.0 kg ha^{-1}. However, 2,4-D EE is a pre-emergent herbicide and it can be applied at 4-5 DAT, which may kill certain grasses too besides sedges and broad leaved weeds. For broad spectrum weed control, 2,4-D can be combined with other pre-emergence herbicides like anilofos, butachlor etc. From four leaf stage up to just before the boot stage, rice is most tolerant to application of 2,4-D (Thomas and Abraham, 1998).

Shahi (1985) reported effective control of *Echinocloa crus-galli*, *Echinocloa colonum*, *Cyperus* spp. and other weeds in rice by applying 2,4-D EE at 1 kg ha^{-1} at 4 DAT. De and Mukhopadhyay (1985) showed that pre-emergence application of 2,4-D EE at 1 kg ha^{-1} showed highest weed control efficiency of 84.23 per cent at 45 DAT. Comparing 2,4-D sodium salt at 0.80 kg ha^{-1} and 2,4-D EE at 0.75 to 0.80 kg ha^{-1}, both applied at 7 DAT, both were effective in controlling weeds at 21 DAT, the most effective being 2,4-D sodium salt (Tripathy and Misra, 2000).

2.4.2.4 Anilofos + 2,4-D

Anilofos 0.3 kg + 2,4-D EE 0.8 kg ha^{-1} applied 4 DAT significantly reduced nutrient depletion and dry matter accumulation of weeds, increased N, P and K uptake of rice and resulted in highest rice yields (Pandey and Thakur, 1988). Rao *et al.* (1993) reported highest weed control efficiency of 91.7 per cent at 20 DAT from plots treated with anilofos at 0.3 kg + 2,4-D at 0.3 kg ha^{-1}. Thomas and Sreedevi (1993) reported that anilofos + 2,4-D EE readymix (0.3 + 0.4 kg ha^{-1}) at 10 to12 days after sowing was very effective in controlling almost all type of weeds in direct seeded puddled rice and resulted in highest grain yields.

Khare and Jain (1995) observed that eventhough hand weeding gave the lowest weed biomass and highest weed control efficiency (60 kg ha^{-1} and 91.6 per cent, respectively), it was closely followed by aniloguard plus (anilofos + 2,4-D EE) at 0.4 kg ha^{-1} (72 kg ha^{-1} and 89.9 per cent, respectively). Crop growth and yield parameters were also best with aniloguard plus. Nagaraju *et al.* (1995) found that application of 0.30 kg anilofos + 0.60 kg 2,4-D ha^{-1} at 4 DAT was the most effective weed control treatment, increasing chlorophyll content and giving 49 per cent yield increase over weedy control.

Singh *et al.* (1996) reported that anilofos alone was as effective as in mixtures with 2,4-D in controlling *Echinochloa* spp. Brar *et al.* (1997) reported that *Caesulia axillaris* was effectively controlled by 2,4-D either alone or in combination with anilofos (tank-mixed or applied in sequence). The optimum treatment was 0.4 kg ha^{-1} anilofos applied pre-emergence and 0.6 kg ha^{-1} 2,4-D applied at 20 DAT. Agrawal and Sharma (1997) found that anilofos at 0.45 and 0.60 kg ha^{-1} either alone or in combination with 2,4-D at 0.5 kg ha^{-1} proved to be as effective as hand weeding twice at 20 and 45 days after transplanting for weed control and for attaining good rice yields. In transplanted rice, anilofos + 2,4-D EE (0.3+0.4 kg ha^{-1}) resulted in greatest reduction of weed biomass (Gupta, 1997).

Anilofos + 2,4-D EE (mixed formulation) significantly lowered the population of grasses, sedges and broad leaved weeds (Phogat and Pandey, 1998). Nandal *et al.* (1999) found hand weeding twice at 20 and 40 DAT and anilofos + 2,4-D EE readymix (0.40 + 0.53 kg ha^{-1}) to be equally good with respect to grain yield, yield attributes, reduction in weed population and dry weight.

According to Dhiman *et al.* (1998), in scented rice cv. Haryana Basmati-1, anilofos + 2,4-D EE (readymix) 0.40 + 0.53 kg ha^{-1} was effective in controlling rice weeds. Readymix application of anilofos 0.45 + 2,4-D EE 0.6 kg ha^{-1} applied at 4 DAT had highest weed control efficiency and grain yield compared to controls. Single application of anilofos recorded 22 per cent lower weed control efficiency than readymix application of anilofos + 2,4-D (Avudaithai and Veerabadran, 2000).

2.4.2.5 Anilofos + 2,4-D Followed by 2,4-D Sodium Salt

Application of anilofos + 2,4-D at 0.2 + 0.5 kg ha^{-1} followed by 2,4-D at 1.0 kg ha^{-1} was effective in minimising growth of all the weeds and gave a higher yield compared to hand weeding twice (Rao, 1995).

Rao and Singh (1997) reported that weed control efficiency was highest from two hand weedings, but was not significantly different from the best herbicide treatment of 0.2 kg anilofos + 0.5 kg 2,4-D ha^{-1} pre-emergence followed by 1.0 kg ha^{-1} 2,4-D applied 23 days after transplanting. These two treatments gave the highest grain yields of 5.15 and 4.94 t ha^{-1}, respectively. Grain yield was negatively correlated with weed dry weight.

2.4.2.6 Anilofos + 2,4-D EE Followed by Hand Weeding

Singh *et al.* (2000a) reported that in direct sown rice, pre-emergence mixture of anilofos + 2,4-D EE at 0.3 + 0.5 kg ha^{-1} followed by one hand weeding at 40 days after sowing recorded significantly lower population and dry weight of weeds. This treatment had a carry over effect on the succeeding lentil crop as evidenced by high lentil yield. This treatment also gave the highest grain yield, straw yield and benefit-cost ratio of 2.50.

MATERIALS AND METHODS

3 MATERIALS AND METHODS

The present investigation was carried out to assess the impact of plant population and weed management practices on the performance of basmati rice. The materials used and methods adopted for the field experiment are detailed below.

3.1 EXPERIMENTAL SITE

The experiment was undertaken in Block B of the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The farm is located at 8°30'N latitude, 76°9'E longitude and at an altitude of 29 m above mean sea level.

3.1.1 Climate

A humid tropical climate prevails in the experimental site. The weekly averages of temperature, relative humidity and rainfall during the cropping period were collected from the observatory attached to the Instructional farm and the data are presented in Appendix I and illustrated graphically in Figure1.

The weather condition during the period of study was favourable for the satisfactory growth of the crop.

3.1.2 Cropping Season

The experiment was conducted during *mundakan* season, from September 2001 to January 2002. Sowing in nursery bed, transplanting in main field and harvest were undertaken on 23rd September, 17th October and 20th January respectively.

3.1.3 Soil

Prior to the experiment, composite soil samples were drawn from a depth of 0 to15 cm and analysed for physico-chemical properties and the data are presented in Table 2.

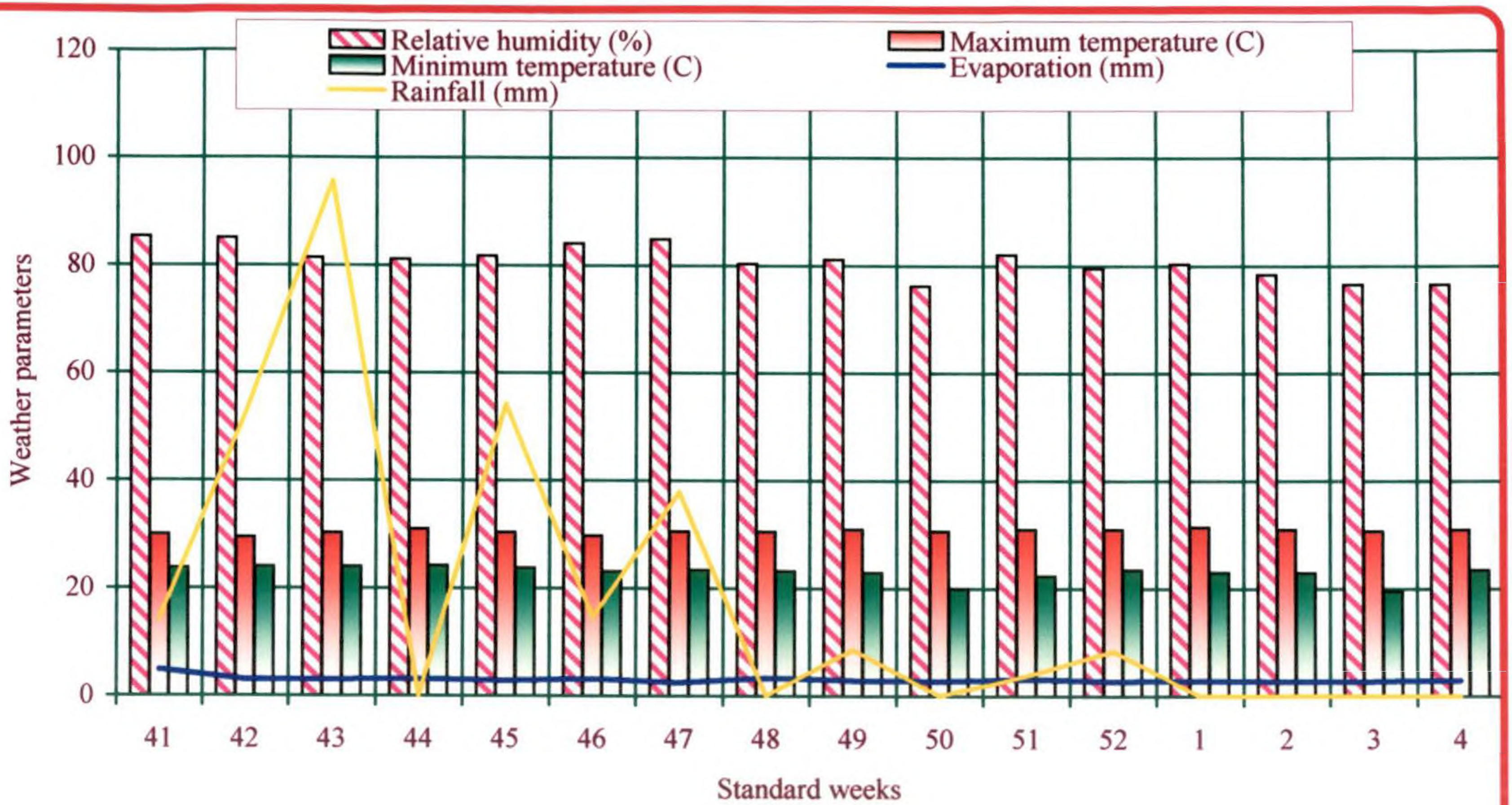


Fig. 1. Weather parameters during the cropping period (September 2001 - January 2002)

The soil of the experimental site was sandy clay loam, belonging to the taxonomical order Oxisol. It was acidic in reaction and medium in available nitrogen and available potassium, and high in available phosphorus and organic carbon content.

Table 2. Soil characteristics of the experimental site

Sl. No.	Fractions	Content in soil	Methods used
A. Mechanical composition			
1.	Coarse sand, %	47.76	Bouyoucos hydrometer method (Bouyoucos, 1962)
2.	Fine sand, %	10.64	
3.	Silt, %	8.60	
4.	Clay, %	33.00	
B. Chemical properties			
1.	Available N, kg ha^{-1}	326.58 (Medium)	Alkaline Permanganate Method (Subbiah and Asija, 1956)
2.	Available P_2O_5, kg ha^{-1}	27.38 (High)	Bray colorimetric Method (Jackson, 1973)
3.	Available K_2O, kg ha^{-1}	174.84 (Medium)	Ammonium acetate Method (Jackson, 1973)
4.	Soil reaction, pH	5.4 (Acidic)	1 : 2 : 5 soil solution ratio using pH meter with glass electrode (Jackson, 1973)
5.	Organic carbon, %	1.69 (High)	Walkley and Black rapid titration method (Jackson, 1973)

3.1.4 Cropping History of the Field

The experimental site was lying fallow for one year prior to the experiment.

3.2 MATERIALS

3.2.1 Crop Variety

The scented rice cv. Pusa Basmati-1 developed at Indian Agricultural Research Institute, New Delhi and released in 1989 was used in the study. Pusa Basmati-1 is the first ever dwarf photo insensitive, input responsive high yielding variety. Total crop duration is 130 days; average yield is 3.8 t ha^{-1} with a yield potential of 4.8 t ha^{-1}(Singh *et al.*, 2000b).

3.2.2 Source of Seed Material

The seeds of Pusa Basmati-1 were obtained from National Seeds Corporation, Regional Office, Karamana, Thiruvananthapuram-695002.

3.2.3 Manures and Fertilizers

Farmyard manure with an analytical value of 0.4, 0.3, 0.2 per cent N, P_2O_5, K_2O respectively was used for the experiment. Urea (46 per cent N), mussoriephos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as source of nitrogen (N), phosphorus (P) and potassium (K) respectively.

3.2.4 Herbicides

The pre-emergent combination herbicide Anilophos + 2,4-D ethyl ester readymix and the post-emergent herbicide 2,4-D sodium salt were applied according to treatments.

1. Anilofos + 2,4-D ethyl ester: [S-4-chlorophenyl-N-isopropyl-carbaniloyl methyl]-O, O-dimethylphosphorothioate + Ethyl ester of 2,4-dichlorophenoxy acetic acid

Formulation:	Anilofos 24% + 2,4-D ethyl ester32% EC
Trade name:	One shot
Manufacturer:	Agro Evo
Price:	Rs 450 l^{-1}

2. 2,4-D sodium salt: Sodium salt of 2,4-dichlorophenoxy acetic acid

Formulation:	2,4-D sodium salt 80 % WP
Trade name:	Kilharb
Manufacturer:	Tropical Agro system (India) Ltd
Price:	Rs 190 l^{-1}

3.3 METHODS

3.3.1 Design and Layout

The detailed layout plan of the experiment is given in Figure 2.

Experimental design	: Randomised Block Design with 2 factors
Number of treatment combinations	: 15
Number of replications	: 3
Gross plot size	: 6.0 x 3.6 m^2
Net plot size	: 4.5 x 2.4 m^2
Total number of plots	: 45

Two rows of plants were left as border on all the sides and the observations were taken from the net plot area.

3.3.2 Treatment Details of the Experiment

1. Spacing: (S)

S_1 – 15 x 15 cm

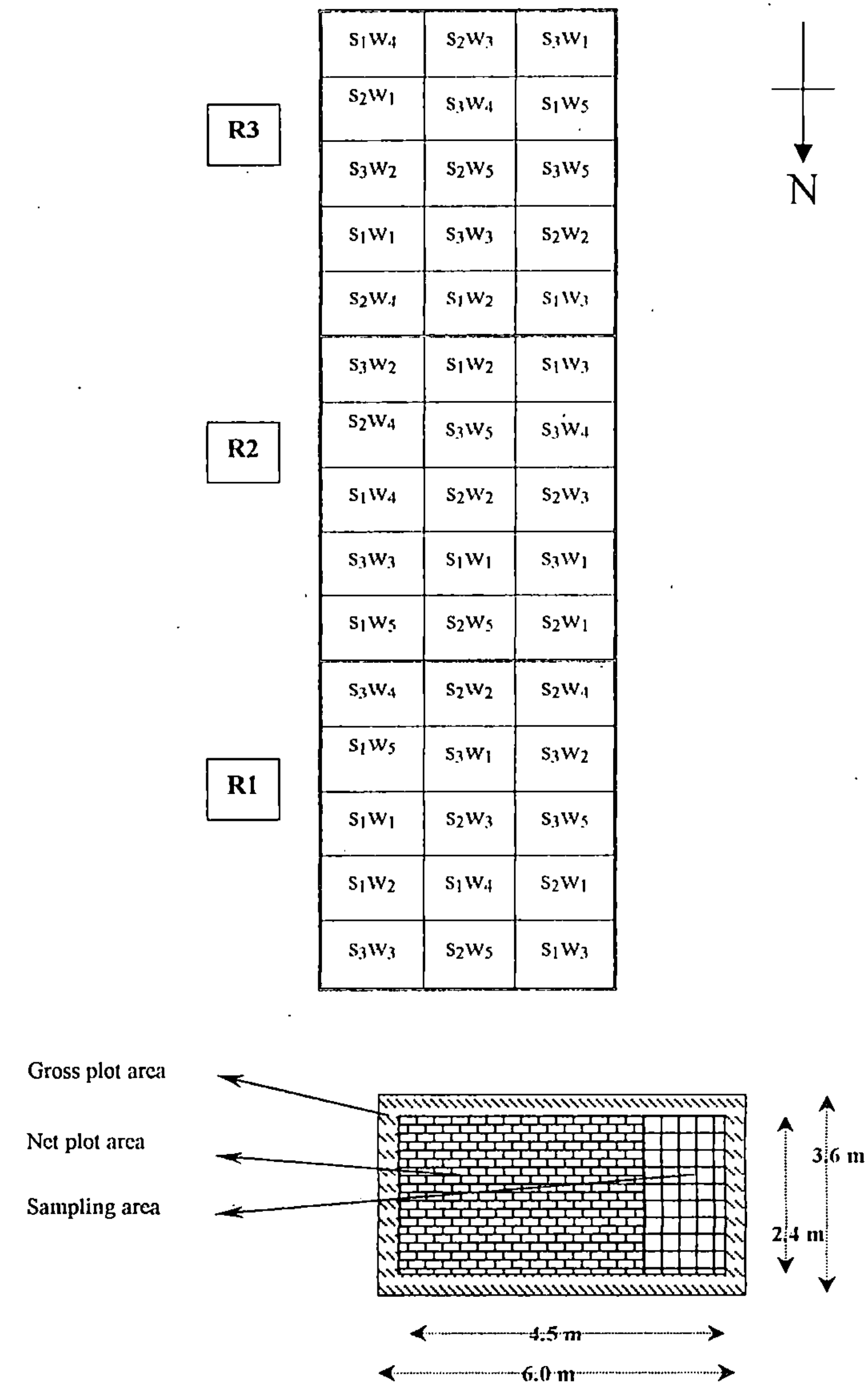
S_2 – 20 x 10 cm

S_3 – 15 x 10 cm

2. Weed management practices: (W)

W_1 - Anilofos + 2,4 – DEE @ 0.4+ 0.53 kg ai ha^{-1} at 6 DAT followed by one hand weeding at 20 DAT

Fig. 2. Layout of the experimental field –RBD with two factors (3 x 5)



W_2 -	Anilofos + 2,4 – DEE @ 0.4+ 0.53 kg ai ha^{-1} at 6 DAT followed by 2,4– D sodium salt @1 kg ai ha^{-1}at 20 DAT
W_3 -	Hand weeding twice at 20 and 40 DAT
W_4 -	Weed free check
W_5 -	Unweeded control

3.3.3 Cultural Practices

All cultural practices except weed management were carried out as per Package of Practices Recommendations 'Crops' (KAU, 1996).

3.3.3.1 Nursery

Nursery was prepared and seeds were sown in the nursery at the rate of 80 kg ha^{-1} on 23rd September 2001.

3.3.3.2 Main Field Preparation

The experimental area was well ploughed, puddled, levelled and weeds and stubbles were removed. Three blocks with fifteen plots each were laid out. The plots were separated with bunds of 30 cm thickness and blocks with bunds of 50 cm thickness. Individual plots were perfectly levelled.

3.3.3.3 Application of Manures and Fertilizers

Farmyard manure was applied to all plots at the rate of 5 t ha^{-1}. Urea, mussoriephos and muriate of potash were applied to supply N, P_2O_5 and K_2O at the rate of 90, 45 and 45 kg ha^{-1} respectively (KAU, 1996)

Two-third dose of N, full dose of P_2O_5 and half dose of K_2O were applied as basal dose. The remaining doses of N and K_2O were applied at panicle initiation stage to all treatments.

3.3.3.4 Transplanting

Twenty four day old, healthy seedlings were gently uprooted from nursery, roots washed and transplanted in the main field at the rate of 3 seedlings $hill^{-1}$.

3.3.3.5 Weed Management

Weeding as per treatments was done.

3.3.3.6 Plant Protection

One spray of methyl parathion (0.05 percent) was given against rice bug and was followed by one spray of carbendazim 500 g ha^{-1} against sheath rot disease.

3.3.3.7 Harvest

The net plot area was harvested separately, threshed, winnowed and weight of grains and straw from individual plots were recorded.

3.4 OBSERVATIONS ON CROP

Five plants were selected at random from the net plot area of each plot and tagged. The following observations were recorded from these sample plants and the mean values worked out.

3.4.1 Crop Growth Characters

3.4.1.1 Plant Height

Plant height was recorded at 20, 40 and 60 DAT and at harvest using the method described by Gomez (1972). The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest ear head, whichever was taller and the average was recorded in centimetres.

3.4.1.2 Number of Tillers per Hill

Tiller count was taken from five randomly selected hills at 20, 40 and 60 DAT and at harvest and expressed as number of tillers per hill.

3.4.1.3 Leaf Area Index (LAI)

Leaf area index was computed at panicle initiation stage using the method described by Gomez (1972). The maximum width 'w' and length 'l' of all leaves of the middle most tiller of five sample hills were noted and LAI was calculated using the relationship:

Leaf area of a single leaf = k x l x w

k – Adjustment factor, taken as 0.75 at panicle initiation stage

$$\text{Leaf area per hill} = \text{Leaf area of middle most tiller} \times \text{Total number of tillers}$$

$$\text{LAI} = \frac{\text{Sum of leaf area per hill of five sample hills in cm}^2}{\text{Area of land covered by five sample hills in cm}^2}$$

3.4.1.4 Dry Matter Production

From each plot, five sample hills were uprooted at 20, 40 and 60 DAT and at harvest. They were washed and dried in shade and then in a hot air oven at 80 ± 5 ^{0}C till a constant weight is attained. Their dry weight was found out and dry matter production expressed in kg ha^{-1}.

3.4.2. Crop Yield Attributes

3.4.2.1 Number of Productive Tillers

At harvest the number of productive tillers were noted from selected hills in the net plot and was expressed as number of productive tillers per hill.

3.4.2.2 Weight of Panicle

From each sample hill, ten panicles were selected at random and all panicles were weighed and mean weight per panicle was determined and expressed in grams.

3.4.2.3 Number of Spikelets per Panicle

The central panicle from each sample hill was threshed separately and the number of spikelets per panicle was counted.

3.4.2.4 Number of Filled Grains per Panicle

The central panicle from each sample hill was threshed separately and the number of filled and unfilled grains was recorded.

3.4.2.5 Sterility Percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.4.2.6 Thousand Grain Weight

From the values obtained from number of filled grains per panicle, thousand grain weight was calculated in grams and adjusted to 14% moisture using the method suggested by Gomez (1972).

$$\text{Thousand grain weight} = \frac{100 - M \times W}{86 \quad \times f} \times 100$$

were 'M' is the moisture content of grains, 'W' is the weight of filled grains and 'f' is the number of filled grains.

3.4.2.7 Grain Yield

The net plot area was harvested individually, threshed, dried, winnowed and dry weight was recorded as kg ha^{-1} after adjusting to 14 percent moisture.

3.4.2.8 Straw Yield

Straw harvested from each net plot was dried under sun to a constant weight and the weight was expressed as kg ha^{-1}.

3.4.2.9 Harvest Index (HI)

From grain yield and straw yield values, the harvest index was worked out using the following equation as suggested by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.2.10 Weed Index (WI)

Weed index was calculated using the equation suggested by Gill and Vijayakumar (1969).

$$WI = \frac{X - Y}{X} \times 100$$ where

X = Yield from weed free plot or treatment, which recorded the minimum number of weeds.

Y = Yield from the plot for which weed index is to be computed.

3.5 OBSERVATIONS ON WEEDS

In the net plot area of each plot, quadrant of size 25 x 25 cm was placed at random at four sites. The following observations were recorded from weeds in this area and average values worked out.

3.5.1 Weed Flora – Grasses, Sedges and Broad leaved

Major weed species that infested the experimental site during the period of experiment were identified and grouped into grasses, sedges and broad leaved weeds.

3.5.2 Weed Dry Matter

Weed samples collected were pulled out along with roots, washed and dried under shade and later they were oven dried at 80 ± 5 ^{0}C to a constant weight. The dry weight of weeds was recorded in whole units and expressed as g m^{-2}.

3.5.3 Weed Control Efficiency (WCE)

Weed control efficiency (WCE) was computed using the method suggested by Mani *et al* (1973).

$$WCE = \frac{WDWC - WDWT}{WDWC} \times 100$$

WDWC = Weed dry weight in unweeded (control) plot.

WDWT = Weed dry weight in treated plot.

3.5.4 Absolute Density (Ad)

Absolute density was computed using the equation suggested by Philips (1959).

Ad = Total number of plants of a given species m^{-2}.

3.5.5 Absolute Frequency (Af)

Absolute frequency was computed using the equation given by Philips (1959).

$$Af = \frac{\text{Number of quadrats in which a given species occurred}}{\text{Total number of quadrats used}} \times 100$$

3.5.6 Relative Density (Rd)

Relative density was computed using the equation given by Philips (1959).

$$Rd = \frac{\text{Absolute density of a species}}{\text{Total absolute density of all species}} \times 100$$

3.5.7 Relative Frequency (Rf)

Relative frequency was computed using the equation given by Philips (1959).

$$Rf = \frac{\text{Absolute frequency of a species}}{\text{Total absolute frequencies of all species}} \times 100$$

3.5.8 Summed Dominance Ratio (SDR)

Summed dominance ratio was computed using the equation given by Sen (1981).

$$SDR = \frac{\text{Relative density} + \text{Relative frequency}}{2}$$

3.5.9 Importance Value (IV)

Importance value of a species indicates the degree of dominance of a species in a given plot and was computed using the formula suggested by Philips (1959).

$$IV = \frac{\text{Dry weight of each species in a community}}{\text{Dry weight of all species in a community}} \times 100$$

3.6 CHEMICAL ANALYSIS

3.6.1 Soil Analysis

Composite soil samples were collected before the start of the experiment and analysed to determine the available N, P_2O_5 and K_2O. The physical composition and pH were also determined. After the harvest of the crop, soil samples were taken from each plot separately and analysed for available N, P_2O_5 and K_2O.

3.6.1.1 Organic Carbon, %

Organic carbon content of soil was estimated by Walkley and Black rapid titration method (Jackson, 1973).

3.6.1.2 Available Nitrogen, N kg ha^{-1}

Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956).

3.6.1.3 Available Phosphorus, P_2O_5 kg ha^{-1}

Available phosphorus was determined by Dickman and Bray's molybdenum blue method in a Klett Summerson photoelectric colorimeter. The soil was extracted with Bray's reagent No. 1 (0.03 N ammonium fluoride in 0.025 N hydrochloric acid) (Jackson, 1973).

3.6.1.4 Available Potassium, K_2O kg ha^{-1}

Available potassium was determined in the neutral normal ammonium acetate extract and estimated using EEL flame photometer (Jackson, 1973).

3.6.2 Nutrient Content of Crop and Weeds

The crop and weed samples collected for dry matter studies were dried to constant weight in an electric hot air oven at 80 ± 5 ^{0}C, ground into fine powder using wiley mill and used for chemical analysis.

3.6.2.1 Total Nitrogen

Total nitrogen was estimated by modified microkjeldhal method (Jackson, 1973).

3.6.2.2 Total Phosphorus Content, %

Total phosphorus content was estimated by vanado molybdo phosphate yellow colour method after extraction with triple acid (9: 4: 1 of HNO_3, H_2SO_4 and $HClO_4$ respectively). The intensity of yellow colour developed was read in a Klett Summerson photoelectric colorimeter at 470 nm (Jackson, 1973).

3.6.2.3 Total Potassium Content, %

The same extract used for phosphorus estimation was used for the estimation of total potassium using EEL flame photometer method (Jackson, 1973).

3.6.3 Nutrient Uptake of Crop and Weeds

The N, P and K uptake by crop and the weeds were worked out as the product of the content of these nutrients and the dry weight of crops or weeds and expressed in kg ha^{-1}.

3.6.4 Scoring of Major Pests like Rice Bug, Stem Borer and Leaf Roller and Diseases like Sheath Blight, Blast and Bacterial Leaf Blight.

Blast, bacterial leaf blight and stem borer attack was not found in the field. Leaf roller and rice bug were found in the field in very low intensities and their count was not significant to be scored.

Sheath blight was severe in the field and scoring of sheath blight incidence was done following a 0 to 9 scoring system (IRRI, 1980). The scoring system adopted is presented in Table 3.

Table 3. Scoring system for sheath blight incidence

Score	Symptom
0	No incidence.
1	Lesions limited to lower ¼th of leaf sheath area.
3	Lesions present on lower ½ of leaf sheath area.
5	Lesions present on more than ½ of lower leaf sheath area
7	Slight infection on upper leaves (mainly on flag and second leaf).
9	Lesions reaching top of tillers. Severe infection on all leaves and some plants killed.

Disease index was worked out using the formula,

$$\text{Disease index} = \frac{\text{Sum of numerical rating x 100}}{\text{Total number of plants observed x Maximum disease category}}$$

3.6.5 Economics of Cultivation

The economics of cultivation was worked out based on the cost of cultivation and prevailing price of the crop produce.

3.6.5.1 Net Income

Net income was computed using the formula,

Net income (Rs ha^{-1}) = Gross income – Total expenditure

3.6.5.2 Benefit - Cost Ratio (BCR)

Benefit-cost ratio was computed using the formula,

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.6.6 Statistical Analysis

The data generated were subjected to analysis of variance (ANOVA) as applied to factorial randomised block design (Panse and Sukhatme, 1985). The data that do not satisfy the basic assumptions of ANOVA were appropriately transformed and the transformed values were used for analysis of variance. For weed data, plots with no variation (treatment combinations involving W_4 and W_5) were not used in statistical analysis. Important correlation coefficients were estimated and tested for their significance (Snedecor and Cochran, 1967).

RESULTS

4 RESULTS

A field experiment was conducted at the Instructional farm, College of Agriculture, Vellayani to assess the impact of plant population and weed management practices on the performance of basmati rice. The data recorded were analysed statistically and the results are presented in this chapter.

4.1 OBSERVATION ON CROP

4.1.1 Crop Growth Characters

Observations on crop growth characters like plant height, tiller number per hill, leaf area index and crop dry matter production were collected from five randomly selected hills from the net plot area.

4.1.1.1 Plant Height

The data summarised in Table 4a and 4b show that the influence of spacing on plant height was significant at 20, 40 and 60 DAT and at harvest. At 20 DAT, the closest spacing of 15 x 10 cm (S_3) recorded the maximum plant height (43.2 cm) and it was significantly superior to other spacings. The widest spacing of 15 x 15 cm (S_1) recorded the minimum plant height of 40.16 cm. But at 40 and 60 DAT and at harvest, the plots with the medium spacing of 20 x 10 cm (S_2), which is the recommended spacing for the medium duration rice in the state, recorded the highest plant height, which was significantly superior to other two spacings tried. The plots having the closest spacing of 15 x 10 cm (S_3) having 34 per cent more population than S_2 recorded the minimum plant height and it was significantly inferior to other spacings.

At all growth stages, the weed management practices influenced plant height significantly. The weed free check (W_4) recorded the maximum value and it was significantly superior to all other weed management treatments. W_2 and W_1 were the next best treatments, W_2 being superior to W_1 and these treatments were significantly superior to the treatment that received two hand weedings (W_3). The unweeded control plots (W_5) recorded the minimum values and it was

Table 4a. Main effect of spacing and weed management practices on plant height, cm

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	40.16	73.71	93.47	112.09
S_2	41.54	76.03	96.85	116.09
S_3	43.20	69.91	90.48	104.78
SE	0.33	0.52	0.53	0.94
CD at 5%	0.961	1.506	1.525	2.714
Weed management practices				
W_1	41.86	73.60	95.25	114.10
W_2	43.71	77.95	97.69	117.56
W_3	39.25	70.45	92.36	110.01
W_4	45.96	80.51	101.15	121.10
W_5	37.38	63.58	81.55	92.15
SE	0.43	0.67	0.68	1.21
CD at 5%	1.241	1.944	1.969	3.504

Table 4b. Interaction effect of spacing and weed management practices on plant height, cm

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	40.34	74.27	95.32	115.89
s_1w_2	41.77	78.56	98.43	119.06
s_1w_3	38.21	70.87	91.84	111.43
s_1w_4	44.35	80.35	101.72	123.76
s_1w_5	36.14	64.50	80.06	90.29
s_2w_1	41.81	76.31	97.31	119.08
s_2w_2	44.18	80.71	100.20	121.92
s_2w_3	38.72	73.69	94.95	115.36
s_2w_4	46.00	83.59	103.36	126.97
s_2w_5	36.97	65.87	88.43	97.13
s_3w_1	43.42	70.21	93.11	107.34
s_3w_2	45.18	74.58	94.44	111.71
s_3w_3	40.83	66.80	90.30	103.24
s_3w_4	47.54	77.61	98.37	112.57
s_3w_5	39.02	60.36	76.16	89.04
SE	0.74	1.16	1.18	2.11
CD at 5%	NS	NS	3.412	NS

Plate 1. General view of the experimental site

significantly inferior to all other treatments at all stages of observation. Only at harvest, the plant height recorded by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was on par with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT).

Interaction effect of spacing and weed management practices was significant at 60 DAT only. Treatment combination s_2w_4 recorded the highest plant height (103.36 cm), which was on par with s_1w_4 and s_2w_2. The treatment combination s_3w_5 recorded the lowest plant height of 76.16 cm, which was significantly lower than other interactions.

4.1.1.2 Number of Tillers per Hill

Number of tillers per hill was recorded at 20, 40 and 60 DAT and at harvest. The results are presented in Tables 5a and 5b. The different spacings did influence number of tillers per hill at all stages of observation. At 20 DAT, the widest spacing of 15 x 15 cm (S_1) recorded the maximum number of tillers per hill of 3.03 and it was significantly superior to other two spacings tried. The closest spacing of 15 x 10 cm (S_3) recorded the minimum number of tillers per hill of 2.64 and it was significantly inferior to other spacings tested. But at 40 and 60 DAT and at harvest, the medium spacing of 20 x 10 cm (S_2) recorded the maximum number of tillers per hill which was significantly higher than that registered by other spacings tested, while the closest spacing of 15 x 10 cm (S_3) recorded the minimum number of tillers per hill showing the same trend as that at 20 DAT.

All weed management treatments influenced number of tillers per hill significantly. At all stages of observation, the weed free check (W_4) and unweeded control (W_5) recorded the maximum and minimum number of tillers per hill respectively. At 20 DAT, maximum number of tillers per hill recorded by weed free check (W_4) was found to be on par with W_2 (pre-emergent anilofos + 2,4-D EE readymix at 6 DAT followed by 2,4-D sodium salt at 20 DAT).

Interaction effect of spacing and weed management practices was significant at 60 DAT only. Treatment combination s_2w_4 recorded the highest

Table 5a. Main effect of spacing and weed management practices on number of tillers per hill

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	3.03	7.92	10.72	9.88
S_2	2.85	8.37	11.65	10.24
S_3	2.64	7.62	9.38	9.09
SE	0.05	0.05	0.09	0.09
CD at 5%	0.149	0.158	0.249	0.251
Weed management practices				
W_1	2.82	8.11	10.64	10.07
W_2	3.20	8.32	11.33	10.64
W_3	2.49	7.69	10.04	9.42
W_4	3.38	9.13	11.96	11.38
W_5	2.31	6.60	8.94	7.18
SE	0.07	0.07	0.11	0.11
CD at 5%	0.192	0.201	0.321	0.324

Table 5b. Interaction effect of spacing and weed management practices on number of tillers per hill

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	3.00	8.20	10.73	10.20
s_1w_2	3.47	8.47	11.40	10.73
s_1w_3	2.37	7.60	10.60	9.47
s_1w_4	3.67	8.93	12.27	11.60
s_1w_5	2.33	6.40	8.60	7.40
s_2w_1	2.93	8.33	11.47	10.53
s_2w_2	3.13	8.60	12.20	11.33
s_2w_3	2.53	8.13	11.13	10.20
s_2w_4	3.33	9.60	12.67	11.67
s_2w_5	2.33	7.20	10.80	7.47
s_3w_1	2.53	7.80	9.73	9.47
s_3w_2	3.00	7.90	10.40	9.87
s_3w_3	2.67	7.33	8.40	8.60
s_3w_4	3.13	8.87	10.93	10.87
s_3w_5	2.27	6.20	7.43	6.67
SE	0.11	0.12	0.19	0.19
CD at 5%	NS	NS	0.556	NS

number of tillers per hill (12.67), which was on par with s_1w_4 and s_2w_2 while s_3w_5 was significantly inferior to rest of the treatment combinations.

4.1.1.3 Dry Matter Production (DMP)

The effect of spacing on DMP was significant at all stages of growth (Tables 6a and 6b). At 20 DAT, the closest spacing of 15 x 10 cm (S_3) recorded the highest DMP and the widest spacing of 15 x 15 cm (S_1) recorded the lowest DMP. But at all other stages of observation, the closest spacing of 15 x 10 cm (S_3) was the least effective treatment and significantly lowered the DMP compared to other spacings. At these stages, the medium spacing of 15 x 10 cm (S_2) recorded significantly more DMP.

Applied weed management practices exerted significant effect on DMP during all stages of observation. At all growth stages, the weed free check (W_4) and unweeded control (W_5) recorded the maximum and minimum DMP respectively. At 20 DAT, weed free check (W_4) was followed by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT), which was on par with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT). At 60 DAT, maximum DMP recorded by weed free check (W_4) was on par with chemical treatments alone (W_2) which in turn was on par with chemical combined with hand weeding treatment (W_1).

Interaction effect of spacing and weed management practices on DMP was significant at all stages of growth. At 20 DAT, s_3w_4 recorded the maximum DMP (1312.62 kg ha^{-1}), which was followed, by s_3w_2 (1164.73) and s_3w_1 (1144.4) and s_1w_5 recorded the lowest DMP (542.12 kg ha^{-1}), which was on par with s_1w_3. Treatment combinations s_1w_2, s_3w_3 and s_1w_1 were found to be comparable. At all other stages of observation, s_2w_4 recorded the highest DMP. At 40 DAT and at harvest this was significantly superior to other interactions. At 40 and 60 DAT and at harvest, treatment combinations s_2w_2 and s_2w_1 were comparable and s_3w_5 recorded the lowest DMP. This treatment combination (s_3w_5) was significantly inferior to all other interactions at both 60 DAT and at harvest.

Table 6a. Main effect of spacing and weed management practices on dry matter production, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	701.82	3987.28	7210.27	9833.97
S_2	788.74	4618.32	8696.39	10999.16
S_3	1020.60	3190.29	6695.97	8449.11
SE	6.22	44.10	68.30	62.86
CD at 5%	18.017	127.733	197.826	182.066
Weed management practices				
W_1	918.72	4165.29	8048.59	10137.90
W_2	928.42	4383.37	8175.79	10788.58
W_3	669.61	3517.90	7670.75	9480.06
W_4	1038.46	4795.17	8309.21	11637.30
W_5	630.04	2798.11	5466.71	6759.90
SE	8.03	56.94	88.18	81.15
CD at 5%	23.261	164.902	255.393	235.046

Table 6b. Interaction effect of spacing and weed management practices on dry matter production, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	754.97	4321.05	7416.94	10235.17
s_1w_2	784.11	4713.26	7473.33	10680.52
s_1w_3	571.63	3371.80	7242.87	9641.91
s_1w_4	856.29	4957.81	7573.30	11766.59
s_1w_5	542.12	2572.49	6344.93	6845.66
s_2w_1	856.81	4790.51	9367.84	11512.40
s_2w_2	836.42	4879.28	9548.75	11851.21
s_2w_3	673.99	4373.68	9292.67	11269.45
s_2w_4	946.46	5694.30	9664.09	12482.47
s_2w_5	629.99	3353.82	5608.57	7880.30
s_3w_1	1144.40	3384.29	7360.98	8666.15
s_3w_2	1164.73	3557.55	7505.29	9834.01
s_3w_3	763.22	2808.20	6476.70	7528.82
s_3w_4	1312.62	3733.39	7690.24	10662.85
s_3w_5	718.02	2468.01	4446.62	5553.75
SE	13.91	98.62	152.73	140.56
CD at 5%	40.289	285.620	442.354	407.111

Plate 2. S_2W_2 at 40 DAT: Plots transplanted at a spacing of 20 x 10 cm and treated with anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT

4.1.1.4 Leaf Area Index (LAI)

Perusal of the data presented in Tables 7a and 7b showed that LAI varied significantly due to spacings. Among different spacing tried, the medium spacing of 20 x 10 cm (S_2) recorded the highest LAI of 4.65, which was significantly superior to the rest of the treatments. The closest spacing of 15 x 10 cm (S_3) recorded the lowest LAI of 3.47.

Weed management practices also exerted significant influence on LAI. The weed free check (W_4) recorded the highest LAI of 5.08 and it was significantly superior to all other weed control treatments. The herbicide treatments were the next best with the LAI of 4.53 and 4.27 and the hand weeding twice treatment (W_3) recorded an LAI of 3.92. Unweeded control (W_5) recorded the lowest LAI of 2.88, which was significantly inferior to all other treatments.

The interaction effect between medium spacing of 20 x 10 cm and weed free treatment (s_2w_4) was most effective in increasing LAI. This was followed by s_1w_4 and s_2w_2. The treatment combination (s_2w_2) was found to be on par with s_1w_2 and s_2w_1. s_3w_5 recorded the lowest LAI which was on par with s_1w_5.

4.1.2 Yield Attributing Characters

4.1.2.1 Number of Productive Tillers per Hill

It could be seen from data presented in Tables 7a and 7b that the medium spacing of 20 x 10 cm (S_2) recorded the highest number of productive tillers per hill (9.25) while the closest spacing of 15 x 10 cm (S_3) recorded the lowest value (8.12), which was significantly inferior to all other treatments. With regard to weed management practices, the same trend as that of LAI was recorded with the weed free treatment (W_4) registering the highest number of productive tillers per hill. The interaction effect of the factors was not significant with respect to number of productive tillers per hill.

Table 7a. Main effect of spacing and weed management practices on leaf area index at panicle initiation stage, number of productive tillers per hill and weight of panicle

Treatments	Leaf area index at panicle initiation stage	Number of productive tillers per hill	Weight of panicle, g
Spacing			
S_1	4.30	8.89	2.63
S_2	4.65	9.25	2.84
S_3	3.47	8.12	1.85
SE	0.04	0.71	0.07
CD at 5%	0.130	0.207	0.207
Weed management practices			
W_1	4.27	9.00	2.53
W_2	4.53	9.40	2.68
W_3	3.92	8.36	2.38
W_4	5.08	10.13	2.96
W_5	2.88	6.86	1.64
SE	0.06	0.09	0.09
CD at 5%	0.168	0.267	0.267

Table 7b. Interaction effect of spacing and weed management practices on leaf area index at panicle initiation stage, number of productive tillers per hill and weight of panicle

Treatment combinations	Leaf area index at panicle initiation stage	Number of productive tillers per hill	Weight of panicle, g
s_1w_1	4.49	9.26	2.76
s_1w_2	4.77	9.53	2.79
s_1w_3	4.12	8.50	2.58
s_1w_4	5.24	10.12	3.33
s_1w_5	2.86	7.02	1.68
s_2w_1	4.73	9.35	2.91
s_2w_2	4.90	9.89	3.16
s_2w_3	4.57	8.66	2.76
s_2w_4	5.85	10.89	3.41
s_2w_5	3.18	7.44	1.94
s_3w_1	3.59	8.39	1.92
s_3w_2	3.94	8.76	2.09
s_3w_3	3.07	7.93	1.81
s_3w_4	4.16	9.38	2.13
s_3w_5	2.60	6.12	1.29
SE	0.10	0.16	0.16
CD at 5%	0.290	NS	NS

Plate 3. S_1W_3 at 40 DAT: Plots transplanted at a spacing of 15 x 15 cm and hand weeded twice at 20 and 40 DAT

4.1.2.2 Weight of Panicle

The closest spacing of 15 x 10 cm (S_3) was inferior to the rest of the treatments (Tables 7a and 7b). The medium spacing of 20 x 10 cm (S_2) was comparable with the widest spacing of 15 x 15 cm (S_1). Weed free check (W_4) recorded the highest value and it was significantly superior to all other weed control treatments. It was followed by W_2 and W_1 which were on par. While treatments involving herbicides (W_2 and W_1) recorded comparable values, hand weeding twice (W_3) was found to be as effective as W_1 (Pre-emergent anilofos + 2,4-D EE readymix at 6 DAT followed by hand weeding at 20 DAT) in increasing the panicle weight. The S x W interactions were not significant with respect to weight of panicle.

4.1.2.3 Number of Spikelets per Panicle

The data on number of spikelets per panicle presented in Tables 8a and 8b reveals that medium spacing of 20 x 10 cm (S_2) recorded the highest number of 141.47 while the closest spacing of 15 x 10 cm (S_3) recorded the lowest number of 116.74.

As in case of panicle weight, the weed free treatment (W_4) and unweeded control (W_5) recorded the highest and lowest number of spikelets per panicle of 147.37 and 102.63 respectively. Treatments W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was comparable with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) in terms of increasing the number of spikelets per panicle. S x W *interactions had no significant impact* on this yield attribute.

4.1.2.4 Number of Filled Grains per Panicle

Both spacing and weed management practices had a significant influence on number of filled grains per panicle (Tables 8a and 8b). The medium spacing (S_2) and the weed free treatment (W_4) were significantly superior to the rest of the treatments while closest spacing (S_3) and unweeded treatment (W_5) registered the

Table 8a. Main effect of spacing and weed management practices on number of spikelets per panicle, number of filled grains per panicle and chaff percentage

Treatments	Number of spikelets per panicle	Number of filled grains per panicle	Chaff percentage
Spacing			
S_1	135.04	113.25	16.55
S_2	141.47	120.15	15.32
S_3	116.74	95.11	18.89
SE	1.39	1.11	0.49
CD at 5%	4.029	3.213	1.415
Weed management practices			
W_1	136.98	115.37	15.94
W_2	141.11	119.95	15.15
W_3	127.34	104.95	17.62
W_4	147.37	127.46	13.56
W_5	102.63	79.76	22.31
SE	1.80	1.43	0.63
CD at 5%	5.201	4.148	1.826

Table 8b. Interaction effect of spacing and weed management practices on number of spikelets per panicle, number of filled grains per panicle and chaff percentage

Treatment *combinations*	Number of spikelets *per panicle*	Number of filled grains *per panicle*	Chaff *percentage*
s_1w_1	139.92	119.11	14.88
s_1w_2	146.93	125.47	14.61
s_1w_3	130.59	107.75	17.51
s_1w_4	150.01	131.85	12.10
s_1w_5	107.76	82.07	23.64
s_2w_1	149.65	128.17	14.35
s_2w_2	153.58	132.82	13.52
s_2w_3	136.95	113.96	16.73
s_2w_4	160.14	138.65	13.41
s_2w_5	107.03	87.12	18.56
s_3w_1	121.38	98.83	18.60
s_3w_2	122.82	101.57	17.31
s_3w_3	114.47	93.16	18.62
s_3w_4	131.96	111.90	15.18
s_3w_5	93.09	70.09	24.72
SE	3.11	2.48	1.09
CD at 5%	NS	NS	NS

Plate 4. S_3W_3 at 40 DAT: Plots transplanted at a spacing of 15 x 10 cm and hand weeded twice at 20 and 40 DAT

least values. The interaction effects had no significant impact on number of filled grains per panicle.

4.1.2.5 Chaff Percentage

Data on chaff percentage (Tables 8a and 8b) shows that closest spacing of 15 x 10 cm (S_3) is significantly inferior to rest of the treatments while S_2 and S_1 recorded comparable values. Weed management treatments also influenced chaff percentage with unweeded control treatment (W_5) being significantly inferior to all other treatments. Use of herbicides alone (W_2) was comparable with weed free treatment (W_4) in determining the chaff percentage. The interaction effect of the factors failed to have a significant impact on this parameter.

4.1.2.6 Thousand Grain Weight

Of the different spacings and weed management practices tried, the medium spacing (S_2) and the weed free treatment (W_4) were significantly superior to all other treatments (Tables 9a and 9b). The treatment involving herbicides alone for weed management (W_2) showed significant increase in thousand grain weight and was inferior only to weed free treatment (W_4). The closest spacing (S_3) and unweeded treatment (W_5) recorded the lowest values. There was no significant interaction between spacing and weed management practices as far as thousand grain weight is concerned.

4.1.2.7 Grain Yield

The different spacings (S) and weed management practices (W) tried had a significant impact on grain yield (Tables 9a and 9b). The medium spacing (S_2) recorded the highest grain yield (3991.19 kg ha^{-1}) while the closest spacing (S_3) recorded the lowest value (3013.75 kg ha^{-1}), which was significantly inferior to rest of the treatments. Among weed management practices, weed free treatment (W_4) recorded significantly higher grain yield. W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) recorded a grain yield of 3927.85 kg ha^{-1}, which was second only to W_4 (weed free treatment) and significantly higher

Table 9a. Main effect of spacing and weed management practices on thousand grain weight, grain yield and straw yield

Treatments	Thousand grain weight, g	Grain yield, kg ha^{-1}	Straw yield, kg ha^{-1}
Spacing			
S_1	23.29	3509.09	6324.88
S_2	23.69	3991.19	7007.97
S_3	22.66	3013.75	5435.37
SE	0.20	23.83	41.48
CD at 5%	0.586	69.022	120.132
Weed management practices			
W_1	23.26	3645.19	6492.71
W_2	23.65	3927.85	6860.72
W_3	22.63	3377.62	6102.43
W_4	24.58	4267.38	7369.92
W_5	21.94	2305.32	4454.58
SE	0.12	30.77	53.55
CD at 5%	0.338	89.108	155.089

Table 9b. Interaction effect of spacing and weed management practices on thousand grain weight, grain yield and straw yield

Treatment combinations	Thousand grain weight, g	Grain yield, kg ha^{-1}	Straw yield, kg ha^{-1}
s_1w_1	23.31	3603.04	6632.13
s_1w_2	23.74	3917.05	6763.46
s_1w_3	22.57	3361.90	6280.01
s_1w_4	24.80	4326.07	7440.51
s_1w_5	22.05	2337.38	4508.28
s_2w_1	23.82	4200.18	7312.22
s_2w_2	24.19	4378.99	7472.22
s_2w_3	23.03	4021.74	7247.70
s_2w_4	25.27	4631.53	7850.93
s_2w_5	22.13	2723.50	5156.80
s_3w_1	22.66	3132.36	5533.79
s_3w_2	23.03	3487.51	6346.50
s_3w_3	22.29	2749.23	4779.59
s_3w_4	23.68	3844.54	6818.31
s_3w_5	21.63	1855.09	3698.66
SE	0.20	53.29	92.75
CD at 5%	NS	154.339	268.622

than W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT). The unweeded treatment (W_5) recorded the lowest grain yield and it was significantly inferior to all other treatments.

The interaction effect of spacing and weed management practices significantly influenced the grain yield with s_2w_4 recording significantly higher value (4631.53 kg ha^{-1}) compared to all other treatment combinations. Grain yield from s_1w_4 was comparable with s_2w_2. Treatment combination s_3w_5 recorded the lowest grain yield of 1855.09 kg ha^{-1} and it was significantly inferior to all other treatment combinations.

4.1.2.8 Straw Yield

It could be observed from data summarised in Tables 9a and 9b that the effect of spacing (S) and weed management (W) on straw yield was similar to the effect of the spacing and weed management practices on grain yield. Straw yield was influenced by interaction effect of spacing and weed management practices with s_2w_4 recording the highest straw yield of 7850.93 kg ha^{-1}. This interaction was significantly superior to all other treatment combinations. Straw yields of s_2w_2, s_1w_4, s_2w_1 and s_2w_3 were comparable among themselves. Treatment combination s_3w_5 recorded the lowest straw yield of 3698.66 kg ha^{-1}, which was significantly inferior to all other interactions.

4.1.2.9 Harvest Index

The different spacing and weed management practices tried had a significant effect on harvest index (Tables 10a and 10b) with medium spacing (S_2) recording significantly higher value of 0.363, while the closest spacing (S_3) recorded significantly inferior values. Harvest index of W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was on par with W_4 (weed free treatment and both were in turn superior to W_3 (hand weeding twice) and W_1 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT). Treatment W_5 (unweeded treatment) recorded the lowest value of 0.34 and it was significantly inferior to all other treatments. None of the harvest index values

Table 10a. Main effect of spacing and weed management practices on harvest index and weed index

Treatments	Harvest index	Weed index
Spacing		
S_1	0.359	18.88
S_2	0.363	13.83
S_3	0.350	21.62
SE	0.001	0.20
CD at 5%	0.0025	0.577
Weed management practices		
W_1	0.359	14.85
W_2	0.364	8.06
W_3	0.357	21.31
W_4	0.366	0.00
W_5	0.340	46.30
SE	0.001	0.26
CD at 5%	0.0033	0.745

Table 10b. Interaction effect of spacing and weed management practices on harvest index and weed index

Treatment combinations	Harvest index	Weed index
s_1w_1	0.362	16.70
s_1w_2	0.367	9.44
s_1w_3	0.357	22.27
s_1w_4	0.368	0.00
s_1w_5	0.341	45.96
s_2w_1	0.365	9.32
s_2w_2	0.370	5.45
s_2w_3	0.365	13.16
s_2w_4	0.371	0.00
s_2w_5	0.346	41.19
s_3w_1	0.352	18.53
s_3w_2	0.355	9.29
s_3w_3	0.349	28.49
s_3w_4	0.360	0.00
s_3w_5	0.334	51.76
SE	0.002	0.45
CD at 5%	NS	1.29

were significantly influenced by the interaction effect of spacing and weed management practices.

4.1.2.10 Weed Index

It could be seen from data presented in Tables 10a and 10b that medium spacing (S_2) was significantly superior to all other spacings tried as it recorded the least weed index of 13.83. The closest spacing (S_3) recorded the maximum weed index of 21.62 and it was significantly inferior to all other treatments. Among the different weed management practices tried, the weed index of weed free treatment (W_4) was as expected. This treatment was closely followed by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT). Both herbicide treatments (W_1 and W_2) were significantly superior to hand weeding twice (W_3). The unweeded treatment (W_5) recorded the least weed index of 46.30 and it was significantly inferior to all other treatments.

The performance of S x W interactions involving W_4 (weed free check) was as expected and comparable among themselves. Treatment combination s_2w_2 was closer to those interactions involving W_4, thus indicating the superiority of this interaction over others. The highest weed index was recorded by s_3w_5 and it was significantly inferior to all other interactions.

4.2 OBSERVATION ON WEEDS

Observations on weeds were gathered from the area set apart for that purpose. The data were statistically analysed after appropriately transforming the data.

4.2.1 Major Weed Flora in Experimental Field

The different weed species observed in experimental field were identified and categorised into grasses, sedges and broad leaved weeds. The detailed list of all weed species observed were summarised in Table 11. *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv. and *Leersia hexandra* S. W. were the most important grassy weeds present. Among sedges, *Cyperus iria* L., Table.11. Major weed flora observed in experimental field

Scientific name	Common name	Family
Grasses		
Echinochloa colona (L.) Link	Jungle rice (Kavada*)	Poaceae
Echinochloa crus-galli (L.) Beauv.	Barnyard grass (Kavada*)	Poaceae
Leersia hexandra S.W.	Swamp rice grass (Neervallipullu*)	Poaceae
Panicum repens L.	Torpedo grass (Inchipullu*)	Poaceae
Sedges		
Cyperus iria L.	Yellow nut sedge (Manjakora*)	Cyperaceae
Cyperus difformis L.	Umbrella sedge (Thalekkettan*)	Cyperaceae
Fimbristylis miliaceae (L.) Vahl.	Globe fingerush (Mung*)	Cyperaceae
Schoenoplectus articulatus (L.)	Bulrush (Pongancheily*)	Cyperaceae
Broadleaved weeds		
Ammania baccifera L.	Blistering ammania (Nellicheera*)	Lythraceae
Hydrilla verticellata (Linn. F.) Royle.	Hydrilla (Mullanpayal*)	Hydrocharitaceae
Ludwigia parviflora Roxb.	Water primrose (Neergrambu*)	Onagraceae
Monochoria vaginalis (Burm. F.) Kunth.	Monochoria (Karimkoovalam*)	Pontenderiaceae

* Vernacular name

Cyperus difformis L. and *Fimbristylis miliaceae* (L.) Vahl. were the predominant ones. *Ludwigia parviflora* Roxb. and *Monochoria vaginalis* (Burm. F.) Kunth. were the most problematic broad leaved weeds observed.

4.2.2 Weed Dry Weight

4.2.2.1 Total Weed Dry Weight

Except at 40 DAT, all levels of spacing had a significant impact on weed dry weight (Tables 12a and 12b). At 20 and 60 DAT and at harvest, the widest spacing of 15 x 15 cm (S_1), which recorded the highest weed dry weight was on par with the medium spacing of 20 x 10 cm (S_2).

Among the weed management practices, at all stages of observation, weed free check (W_4) was significantly superior to all other treatments since the field was kept weed free. Treatments involving herbicides (W_1 and W_2) was on par among themselves and were superior to hand weeding twice (W_3). The interaction effect between spacing and weed management was not significant at any stages of observation.

4.2.2.2 Dry Weight of Grasses

At all stages of observation, treatments involving widest spacing (S_1) and medium spacing (S_2) were comparable (Tables 13a and 13b). At 40 DAT, the medium spacing (S_2) was on par with the closest spacing. At all other stages of observation, S_3 was significantly superior to other treatments as it registered the lowest dry weight of grasses.

As in case of dry weight of all type of weeds, weedy check (W_5) recorded the highest values. At 20 DAT (just before first manual weeding), the herbicide treatments were comparable among them but were superior to hand weeding twice (W_3). At all other stages of observation, use of herbicides alone (W_2) was effective in reducing the weed dry weight and it was superior to treatments W_1 and W_3. Dry weight of grasses was not affected by S x W interaction at any stages of observation.

Table 12a. Main effect of spacing and weed management practices on total weed dry weight, g m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	14.48	27.80	40.99	40.95
	(3.94)	(5.37)	(6.48)	(6.48)
S_2	14.37	26.24	40.70	39.46
	(3.92)	(5.22)	(6.45)	(6.36)
S_3	13.02	25.20	37.57	36.36
	(3.74)	(5.12)	(6.21)	(6.11)
SE	0.05	0.07	0.05	0.04
CD at 5%	0.144	NS	0.149	0.128
Weed management practices				
W_1	5.54	14.97	38.10	41.34
	(2.56)	(3.00)	(6.25)	(6.51)
W_2	5.31	12.22	17.51	16.56
	(2.51)	(3.64)	(4.30)	(4.19)
W_3	41.47	47.11	56.10	50.63
	(6.52)	(6.94)	(7.56)	(7.19)
W_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
W_5	44.52	111.55	162.84	160.42
	(6.75)	(10.61)	(12.80)	(12.71)
SE	0.06	0.09	0.07	0.09
CD at 5%	0.187	0.262	0.192	0.287

¶ - Transformed values are given in parenthesis

Table 12b. Interaction effect of spacing and weed management practices on total weed dry weight, g m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	5.77	15.94	39.33	43.85
	(2.60)	(4.12)	(6.35)	(6.70)
s_1w_2	5.39	14.13	19.11	18.70
	(2.53)	(3.89)	(4.48)	(4.44)
s_1w_3	42.92	47.29	57.75	52.94
	(6.63)	(6.95)	(7.66)	(7.34)
s_1w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_1w_5	46.84	117.41	165.44	165.55
	(6.92)	(10.88)	(12.90)	(12.91)
s_2w_1	5.88	14.77	39.86	42.91
	(2.62)	(3.97)	(6.39)	(6.63)
s_2w_2	5.56	11.29	18.02	16.17
	(2.56)	(3.51)	(4.36)	(4.15)
s_2w_3	42.42	47.68	57.88	51.42
	(6.59)	(6.98)	(7.67)	(7.24)
s_2w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_2w_5	45.58	112.24	164.43	162.79
	(6.82)	(10.64)	(12.86)	(12.80)
s_3w_1	4.98	8.54	35.21	37.41
	(2.44)	(3.09)	(6.02)	(6.19)
s_3w_2	4.96	11.32	15.52	14.89
	(2.44)	(3.51)	(4.06)	(3.98)
s_3w_3	39.10	46.36	52.79	47.58
	(6.33)	(6.88)	(7.33)	(6.97)
s_3w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_3w_5	41.25	105.14	158.69	153.07
	(6.50)	(10.30)	(12.64)	(12.41)
SE	0.11	0.16	0.12	0.09
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

Table 13a. Main effect of spacing and weed management practices on dry weight of grasses, g m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	9.99	17.23	23.12	22.45
	(3.32)	(4.27)	(4.91)	(4.84)
S_2	9.84	16.06	23.05	21.71
	(3.29)	(4.13)	(4.91)	(4.77)
S_3	8.88	15.53	21.37	19.93
	(3.14)	(4.07)	(4.73)	(4.58)
SE	0.04	0.05	0.04	0.04
CD at 5%	0.113	0.159	0.120	0.103
Weed management practices				
W_1	1.97	8.35	15.07	15.98
	(1.73)	(3.06)	(4.01)	(4.12)
W_2	1.73	6.541	11.17	11.05
	(1.65)	(2.75)	(3.49)	(3.47)
W_3	33.26	22.82	26.50	22.65
	(5.85)	(4.88)	(5.24)	(4.86)
W_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
W_5	35.22	81.66	109.31	102.61
	(6.02)	(9.09)	(10.50)	(10.18)
SE	0.05	0.07	0.05	0.05
CD at 5%	0.146	0.205	0.155	0.132

¶ - Transformed values are given in parenthesis

Table 13b. Interaction effect of spacing and weed management practices on dry weight of grasses, g m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	2.18	8.99	15.33	16.45
	(1.78)	(3.16)	(4.04)	(4.18)
s_1w_2	1.81	7.46	12.14	12.43
	(1.68)	(2.91)	(3.62)	(3.66)
s_1w_3	34.14	23.45	27.42	23.51
	(5.93)	(4.95)	(5.33)	(4.95)
s_1w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_1w_5	37.36	86.15	110.55	107.55
	(6.19)	(9.34)	(10.56)	(10.42)
s_2w_1	2.06	8.23	15.96	16.96
	(1.75)	(3.04)	(4.12)	(4.24)
s_2w_2	1.79	6.09	11.58	10.91
	(1.67)	(2.66)	(3.55)	(3.45)
s_2w_3	34.37	22.28	26:99	23.08
	(5.95)	(4.82)	(5.29)	(4.91)
s_2w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_2w_5	36.08	82.29	110.77	103.61
	(6.09)	(9.13)	(10.57)	(10.23)
s_3w_1	1.69	7.85	13.95	14.58
	(1.64)	(2.97)	(3.87)	(3.95)
s_3w_2	1.62	6.11	9.86	9.90
	(1.62)	(2.67)	(3.30)	(3.30)
s_3w_3	31.30	22.75	25.13	21.39
	(5.68)	(4.87)	(5.11)	(4.73)
s_3w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_3w_5	32.29	76.68	106.66	96.84
	(5.77)	(8.82)	(10.38)	(9.89)
SE	0.09	0.12	0.09	0.08
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

Plate 5. S_1W_3 at harvest: Plots transplanted at a spacing of 15 x 15 cm and hand weeded twice at 20 and 40 DAT

4.2.2.3 Dry Weight of Sedges

As indicated in Tables 14a and 14b, the effect of spacing was significant only at 60 DAT and at harvest. The closest spacing (S_3) was significantly superior while treatments S_1 and S_2 had similar effect on weed dry weight. The main effect of weed management practices and S x W interaction on weed dry weight of sedges was similar to that of weed dry weight of grasses.

4.2.2.4 Dry Weight of Broad Leaved Weeds

Tables 15a and 15b shows the superiority of closest spacing (S_3) in reducing the dry weight of broad leaved weeds at 20 DAT and at harvest. Treatments S_1 and S_2 were comparable at 20 DAT. The trend set by effect of weed management practices was similar to that of weed dry weight of grasses. The interaction effect of factors (S and W) was significant at harvest with treatment combinations s_1w_4, s_2w_4 and s_3w_4 i.e. treatments involving weed free check were comparable among themselves and significantly superior to all others. These combinations were followed by s_3w_2 and s_2w_2 showing the superiority of W_2 in reducing the dry weight of broad leaved weeds.

4.2.3 Weed Control Efficiency (WCE)

4.2.3.1 Total Weed Control Efficiency (WCE)

The data presented in Tables 16a and 16b shows that while the main effect of spacing (S) was insignificant at all stages of observation, the weed control treatments exerted significant influence on weed control efficiency. At all stages the WCE for weed free check (W_4) was taken as hundred and that for unweeded control (W_5) was taken as zero per cent. At 20 and 40 DAT, WCE of treatments W_2 and W_1 were on par but significantly superior to hand weeding twice (W_3). At 60 DAT and at harvest, W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was significantly superior to W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT). The unweeded control (W_5) registered the lowest values during the entire crop period. The interaction effect between spacing and weed management was not significant.

Table 14a. Main effect of spacing and weed management practices on dry weight of sedges, g m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	2.86	8.41	11.31	10.43
	(1.97)	(3.07)	(3.51)	(3.38)
S_2	2.82	8.30	11.10	10.30
	(1.96)	(3.05)	(3.48)	(3.36)
S_3	2.69	7.83	10.12	9.66
	(1.92)	(2.97)	(3.34)	(3.27)
SE	0.02	0.04	0.03	0.02
CD at 5%	NS	NS	0.074	0.069
Weed management practices				
W_1	2.26	5.00	16.41	14.74
	(1.81)	(2.45)	(4.17)	(3.97)
W_2	2.09	3.46	2.98	2.42
	(1.76)	(2.11)	(2.00)	(1.85)
W_3	5.36	19.95	18.19	15.53
	(2.52)	(4.58)	(4.38)	(4.07)
W_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
W_5	6.09	24.10	31.00	32.62
	(2.66)	(5.01)	(5.66)	(5.80)
SE	0.03	0.04	0.03	0.03
CD at 5%	0.089	0.138	0.095	0.089

¶ - Transformed values are given in parenthesis

Table 14b. Interaction effect of spacing and weed management practices on dry weight of sedges, g m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	2.26 (1.80)	5.33 (2.52)	17.23 (4.27)	15.76 (4.09)
s_1w_2	2.09 (1.76)	4.03 (2.24)	3.35 (2.08)	2.81 (1.95)
s_1w_3	5.83 (2.61)	19.50 (4.53)	18.69 (4.44)	15.71 (4.09)
s_1w_4	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
s_1w_5	6.06 (2.66)	24.55 (5.06)	32.08 (5.75)	32.31 (5.77)
s_2w_1	2.39 (1.84)	4.85 (2.42)	17.09 (4.25)	15.31 (4.04)
s_2w_2	2.22 (1.80)	3.19 (2.05)	3.01 (2.00)	2.29 (1.81)
s_2w_3	5.11 (2.47)	21.27 (4.72)	18.96 (4.47)	15.69 (4.09)
s_2w_4	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
s_2w_5	6.14 (2.67)	24.64 (5.06)	31.14 (5.66)	33.45 (5.87)
s_3w_1	2.08 (1.76)	4.83 (2.41)	14.95 (3.99)	13.19 (3.77)
s_3w_2	1.97 (1.72)	3.18 (2.04)	2.59 (1.89)	2.17 (1.78)
s_3w_3	5.15 (2.48)	19.12 (4.49)	16.96 (4.23)	15.19 (4.02)
s_3w_4	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)
s_3w_5	6.07 (2.66)	23.12 (4.91)	29.80 (5.55)	32.07 (5.75)
SE	0.05	0.08	0.05	0.05
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

Table 15a. Main effect of spacing and weed management practices on dry weight of broad leaved weeds, g m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	1.69	2.69	7.25	8.81
	(1.64)	(1.92)	(2.87)	(3.13)
S_2	1.71	2.35	7.231	8.32
	(1.65)	(1.83)	(2.87)	(3.05)
S_3	1.50	2.39	6.79	7.63
	(1.58)	(1.84)	(2.79)	(2.94)
SE	0.02	0.03	0.03	0.02
CD at 5%	0.046	NS	NS	0.065
Weed management practices				
W_1	1.33	1.62	6.62	10.61
	(1.5)	(1.62)	(2.76)	(3.41)
W_2	1.47	2.24	3.37	3.08
	(1.57)	(1.80)	(2.09)	(2.02)
W_3	2.87	4.30	11.40	12.42
	(1.97	(2.30)	(3.52)	(3.66)
W_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
W_5	3.21	5.75	22.50	25.17
	(2.05)	(2.60)	(4.85)	(5.12)
SE	0.020	0.036	0.03	0.03
CD at 5%	0.059	0.103	0.097	0.083

¶ - Transformed values are given in parenthesis

Table 15b. Interaction effect of spacing and weed management practices on dry weight of broad leaved weeds, g m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	1.35	1.61	6.76	11.63
	(1.53)	(1.62)	(2.79)	(3.55)
s_1w_2	1.49	2.64	3.61	3.4
	(1.58	(1.91)	(2.15)	(2.11)
s_1w_3	2.95	4.33	11.63	13.71
	(1.99	(2.31)	(3.55)	(3.84)
s_1w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_1w_5	3.41	6.69	22.80	25.68
	(2.10	(2.77)	(4.88)	(5.17)
s_2w_1	1.43	1.70	6.81	10.62
	(1.56)	(1.64)	(2.79)	(3.41)
s_2w_2	1.55	2.03	3.44	2.98
	(1.60)	(1.74)	(2.11)	(2.00)
s_2w_3	2.93	4.13	11.94	12.64
	(1.98)	(2.26)	(3.60)	(3.69)
s_2w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_2w_5	3.35	5.29	22.51	25.71
	(2.09)	(2.51)	(4.85)	(5.17)
s_3w_1	1.20	1.56	6.30	9.64
	(1.48)	(1.60)	(2.70)	(3.26)
s_3w_2	1.38	2.04	3.08	2.82
	(1.54)	(1.74)	(2.02)	(1.95)
s_3w_3	2.66	4.46	10.68	10.99
	(1.91)	(2.34)	(3.42)	(3.46)
s_3w_4	0.00	0.00	0.00	0.00
	(1.00)	(1.00)	(1.00)	(1.00)
s_3w_5	2.89	5.33	22.21	24.14
	(1.97)	(2.52)	(4.82)	(5.01)
SE	0.04	0.06	0.06	0.05
CD at 5%	NS	NS	NS	0.144

¶ - Transformed values are given in parenthesis

Table 16a. Main effect of spacing and weed management practices on total weed control efficiency, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	51.93	77.42	76.27	76.48
	(7.21)	(8.80)	(8.73)	(8.75)
S_2	50.27	77.26	76.14	77.05
	(7.09)	(8.79)	(8.73)	(8.78)
S_3	49.11	76.30	77.92	77.99
	(7.01)	(8.74)	(8.83)	(8.83)
SE	0.10	0.05	0.03	0.03
CD at 5%	NS	NS	NS	NS
Weed management practices				
W_1	87.52	86.49	76.56	74.22
	(9.36)	(9.30)	(8.75)	(8.62)
W_2	87.98	89.06	89.17	89.64
	(9.38)	(9.44)	(9.44)	(9.47)
W_3	6.59	57.65	65.50	68.43
	(2.57)	(7.59)	(8.09)	(8.27)
W_4	-	-	-	-
W_5	-	-	-	-
SE	0.10	0.05	0.03	0.03
CD at 5%	0.303	0.148	0.103	0.091

¶ - Transformed values are given in parenthesis

Table 16b. Interaction effect of spacing and weed management practices on total weed control efficiency, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	87.64	86.38	76.19	73.50
	(9.36)	(9.29)	(8.73)	(8.57)
s_1w_2	88.46	87.97	88.40	8.64
	(9.41)	(9.38)	(9.40)	(9.42)
s_1w_3	8.12	59.66	65.09	68.01
	(2.85)	(7.72)	(8.07)	(8.25)
s_1w_4	-	-	-	-
s_1w_5	-	-	-	-
s_2w_1	87.03	86.73	75.70	73.61
	(9.33)	(9.31)	(8.70)	(8.58)
s_2w_2	87.75	89.71	88.97	90.02
	(9.37)	(9.47)	(9.43)	(9.49)
s_2w_3	6.62	57.52	64.73	68.36
	(2.57)	(7.58)	(8.05)	(8.27)
s_2w_4	-	-	-	-
s_2w_5	-	-	-	-
s_3w_1	87.90	86.34	77.79	75.56
	(9.38)	(9.29)	(8.82)	(8.69)
s_3w_2	87.76	89.17	90.17	90.26
	(9.37)	(9.44)	(9.50)	(9.50)
s_3w_3	5.20	55.81	66.69	68.89
	(2.28)	(7.47)	(8.17)	(8.30)
s_3w_4	-	-	-	-
s_3w_5	-	-	-	-
SE	0.53	0.09	0.06	0.05
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

4.2.3.2 Weed Control Efficiency (WCE) of Grasses

As depicted in Tables 17a and 17b, the different spacings tried had no significant impact on weed control efficiency of grasses. However it varied significantly due to different weed management practices at all stages of observations. Except at 60 DAT, at all other stages, W_2 was on par with treatments involving herbicides and hand weeding (W_1). Both W_2 (anilofos +2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) and W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) were significantly more efficient than hand weeding twice (W_3) in controlling grasses. There was no significant interaction between spacing and weed management practices.

4.2.3.3 Weed Control Efficiency (WCE) of Sedges

Among all the spacings tried, except at 20 DAT, none were significant (Tables 18a and 18b). At 20 DAT, the closest and medium spacings (S_3 and S_2) were equally effective and significantly superior to the widest spacing (S_1).

The treatments involving herbicides (W_1 and W_2) were on par but significantly superior to hand weeding twice (W_3) at 20 DAT. At all other stages of observation, W_2 (anilofos +2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was significantly superior to W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT), which in turn was significantly superior to W_3 (hand weeding twice). The interaction effect of spacing and weed management was significant at 20 DAT with treatment combinations s_3w_2, s_1w_2, s_3w_1, s_2w_2, s_1w_1 and s_2w_1 on par and significantly superior to all other interactions.

4.2.3.4 Weed Control Efficiency (WCE) of Broad Leaved Weeds

The different spacings tried had a significant impact on weed control efficiency of broad leaved weeds only at harvest with the widest spacing (S_1) significantly inferior to all other treatments with a weed control efficiency of 46.66 per cent (Tables 19a and 19b). The medium spacing (S_2) was on par with

Table 17a. Main effect of spacing and weed management practices on weed control efficiency of grasses, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	55.49	84.31	83.32	82.23
	(7.45)	(9.18)	(9.13)	(9.07)
S_2	50.45	84.88	83.43	83.50
	(7.10)	(9.21)	(9.13)	(9.14)
S_3	49.90	83.63	84.55	83.69
	(7.06)	(9.15)	(9.20)	(9.15)
SE	0.17	0.04	0.03	0.05
CD at 5%	NS	NS	NS	NS
Weed management practices				
W_1	94.38	89.70	86.19	84.42
	(9.72)	(9.47)	(9.28)	(9.19)
W_2	95.02	91.93	89.72	87.70
	(9.95)	(9.59)	(9.47)	(9.37)
W_3	4.64	71.93	75.72	77.48
	(2.15)	(8.48)	(8.70)	(8.80)
W_4	-	-	-	-
W_5	-	-	-	-
SE	0.17	0.04	0.03	0.08
CD at 5%	0.51	0.13	0.08	0.24

¶ - Transformed values are given in parenthesis

Table 17b. Interaction effect of spacing and weed management practices on weed control efficiency of grasses, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	94.16	89.53	86.11	84.70
	(9.70)	(9.46)	(9.28)	(9.20)
s_1w_2	95.13	91.34	88.96	83.96
	(9.75)	(9.56)	(9.43)	(9.16)
s_1w_3	8.36	72.73	75.19	78.13
	(2.89)	(8.53)	(8.67)	(8.84)
s_1w_4	-	-	-	-
s_1w_5	-	-	-	-
s_2w_1	94.24	89.93	85.55	83.60
	(9.71)	(9.48)	(9.25)	(9.14)
s_2w_2	94.90	92.45	89.48	89.43
	(9.74)	(9.62)	(9.46)	(9.46)
s_2w_3	3.44	72.93	75.59	77.66
	(1.85)	(8.54)	(8.69)	(8.81)
s_2w_4	-	-	-	-
s_2w_5	-	-	-	-
s_3w_1	94.74	89.67	86.91	84.94
	(9.73)	(9.47)	(9.32)	(9.22)
s_3w_2	94.90	91.99	90.71	89.76
	(9.74)	(9.59)	(9.52)	(9.47)
s_3w_3	2.94	70.12	76.39	76.62
	(1.72)	(8.37)	(8.74)	(8.75)
s_3w_4	-	-	-	-
s_3w_5	-	-	-	-
SE	0.30	0.08	0.05	0.08
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

Table 18a. Main effect of spacing and weed management practices on weed control efficiency of sedges, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	35.59 (5.97)	56.18 (7.50)	57.30 (7.57)	63.33 (7.96)
S_2	43.48 (6.59)	53.51 (7.32)	55.88 (7.48)	65.50 (8.09)
S_3	44.52 (6.67)	55.29 (7.44)	59.61 (7.72)	67.06 (8.19)
SE	0.15	0.10	0.08	0.07
CD at 5%	0.46	NS	NS	NS
Weed management practices				
W_1	62.84 (7.93)	79.07 (8.89)	46.91 (6.85)	54.64 (7.39)
W_2	65.08 (8.07)	85.45 (9.24)	90.35 (9.51)	92.56 (9.62)
W_3	10.48 (3.24)	16.89 (4.11)	41.10 (6.41)	52.22 (7.23)
W_4	-	-	-	-
W_5	-	-	-	-
SE	0.17	0.04	0.03	0.08
CD at 5%	0.51	0.13	0.08	0.24

¶ - Transformed values are given in parenthesis

Table 18b. Interaction effect of spacing and weed management practices on weed control efficiency of sedges, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	62.77	78.14	46.20	51.17
	(7.92)	(8.84)	(6.80)	(7.15)
s_1w_2	65.49	83.56	89.50	91.34
	(8.09)	(9.14)	(9.46)	(9.56)
s_1w_3	3.54	20.29	41.65	51.30
	(1.88)	(4.50)	(6.45)	(7.16)
s_1w_4	-	-	-	-
s_1w_5	-	-	-	-
s_2w_1	60.54	80.21	44.93	54.07
	(7.78)	(8.96)	(6.70)	(7.35)
s_2w_2	63.23	86.61	90.26	93.13
	(7.95)	(9.31)	(9.50)	(9.65)
s_2w_3	16.40	13.56	38.70	42.94
	(4.05)	(3.68)	(6.22)	(7.28)
s_2w_4	-	-	-	-
s_2w_5	-	-	-	-
s_3w_1	65.26	78.87	49.68	58.84
	(8.08)	(8.88)	(7.05)	(7.67)
s_3w_2	66.53	86.22	91.30	93.20
	(8.16)	(9.29)	(9.56)	(9.65)
s_3w_3	14.29	17.16	43.02	52.43
	(3.78)	(4.14)	(6.56)	(7.24)
s_3w_4	-	-	-	-
s_3w_5	-	-	-	-
SE	0.27	0.17	0.14	0.11
CD at 5%	0.80	NS	NS	NS

¶ - Transformed values are given in parenthesis

Table 19a. Main effect of spacing and weed management practices on weed control efficiency of broad leaved weeds, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	35.12	55.56	66.95	54.17
	(5.93)	(7.45)	(8.18)	(7.36)
S_2	37.50	47.28	66.15	64.98
	(6.12)	(6.68)	(8.13)	(8.06)
S_3	34.34	38.30	69.12	66.81
	(5.86)	(6.19)	(8.31)	(8.17)
SE	0.23	0.36	0.06	0.04
CD at 5%	NS	NS	NS	0.13
Weed management practices				
W_1	58.54	71.10	70.53	57.79
	(7.65)	(8.43)	(8.40)	(7.60)
W_2	53.39	52.88	84.92	87.67
	(7.31)	(7.27)	(9.22)	(9.36)
W_3	8.71	23.18	49.22	50.51
	(2.95)	(4.82)	(7.02)	(7.11)
W_4	-	-	-	-
W_5	-	-	-	-
SE	0.23	0.36	0.06	0.04
CD at 5%	0.69	1.08	0.18	0.13

¶ - Transformed values are given in parenthesis

Table 19b. Interaction effect of spacing and weed management practices on weed control efficiency of broad leaved weeds, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	60.10	75.82	70.33	54.70
	(7.75)	(8.71)	(8.39)	(7.40)
s_1w_2	55.98	60.34	84.07	86.38
	(7.48)	(7.77)	(9.17)	(9.29)
s_1w_3	6.47	34.66	48.85	46.48
	(2.54)	(5.89)	(6.99)	(6.82)
s_1w_4	-	-	-	-
s_1w_5	-	-	-	-
s_2w_1	57.30	66.90	69.67	58.67
	(7.57)	(8.18)	(8.35)	(7.66)
s_2w_2	53.23	61.47	84.65	88.31
	(7.30)	(7.84)	(9.20)	(9.40)
s_2w_3	12.28	21.25	46.94	50.79
	(3.50)	(4.61)	(6.85)	(7.13)
s_2w_4	-	-	-	-
s_2w_5	-	-	-	-
s_3w_1	58.23	70.72	71.56	60.05
	(7.63)	(8.41)	(8.46)	(7.75)
s_3w_2	51.02	38.55	86.04	88.32
	(7.14)	(6.21)	(9.28)	9.40)
s_3w_3	7.88	15.59	51.94	54.40
	(2.81)	(3.95)	(7.21)	(7.38)
s_3w_4	-	-	-	-
s_3w_5	-	-	-	-
SE	0.40	0.63	0.10	0.08
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

Plate 6. S_2W_2 at harvest: Plots transplanted at a spacing of 20 x 10 cm and treated with anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT

the closest spacing (S_3) in controlling broad leaved weeds. At all stages of observation, the weed control efficiency of different weed management practices adopted for controlling broad leaved weeds followed the same trend as those for sedges. None of the S x W interactions were significant.

4.2.4 Absolute Density

4.2.4.1 Total Absolute Weed Density

Data on absolute density of all types of weeds are presented in Tables 20a and 20b. The effect of spacing on absolute density of all types of weeds was significant with the closest spacing (S_3) recording significantly higher values at all stages of observation. Among the weed management practices adopted, at all stages of observation, the absolute density of weeds in W_3 (hand weeding twice) was significantly higher than the herbicide treatments (W_1 and W_2) and hand weeding twice (W_3) but significantly lower than W_5 (unweeded control). Weed free treatment (W_4) was superior to all other treatments and it was closely followed by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT), which in turn was superior to all other treatments.

Interaction effect was significant at 40 and 60 DAT with s_2w_2, s_1w_2 and s_3w_2 (combinations involving the herbicide treatment W_2) significantly superior to all other interactions. At 40 DAT, s_2w_2 was on par with s_1w_2, which was on par with s_3w_2 while at 60 DAT; s_2w_2 interaction was significantly superior to s_1w_2 and s_3w_2. Treatment combination s_3w_5 was significantly inferior to all other interactions.

4.2.4.2 Absolute Density of Grasses

At all stages of observation, the medium spacing (S_2) recorded the lowest absolute density of grasses and was significantly superior to all other spacings (Tables 21a and 21b). Except at 20 DAT, S_3 was significantly inferior to all other treatments. The effect of weed management practices on absolute density of grasses followed the same trend as that of absolute density of all type of weeds.

Table 20a. Main effect of spacing and weed management practices on total absolute weed density, number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	35.69	54.41	88.13	79.64
	(5.98)	(7.38)	(9.39)	(8.93)
S_2	33.02	46.24	79.21	72.90
	(5.75)	(6.80)	(8.90)	(8.54)
S_3	37.69	58.83	96.75	87.09
	(6.14)	(7.67)	(9.84)	(9.33)
SE	0.04	0.04	0.06	0.08
CD at 5%	0.113	0.112	0.169	0.221
Weed management practices				
W_1	9.75	23.53	66.15	53.52
	(3.12)	(4.85)	(8.13)	(7.32)
W_2	7.95	11.02	27.36	31.37
	(2.82)	(3.32)	(5.23)	(5.60)
W_3	74.37	77.95	84.05	70.38
	(8.62)	(8.83)	(9.17)	(8.39)
W_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
W_5	85.47	147.09	224.01	207.88
	(9.25)	(12.13)	(14.97)	(14.42)
SE	0.04	0.04	0.07	0.08
CD at 5%	0.131	0.130	0.196	0.221

¶ - Transformed values are given in parenthesis

Table 20b. Interaction effect of spacing and weed management practices on total absolute weed density, number m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	9.69	24.58	66.46	52.88
	(3.11)	(4.96)	(8.15)	(7.27)
s_1w_2	7.99	11.02	27.89	30.60
	(2.83)	(3.32)	(5.28)	(5.53)
s_1w_3	75.84	78.16	83.76	70.31
	(8.71)	(8.84)	(9.15)	(8.39)
s_1w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_1w_5	85.53	153.41	224.07	210.41
	(9.25)	(12.39)	(14.97)	(14.51)
s_2w_1	8.85	19.69	61.26	49.75
	(2.97)	(4.44)	(7.83)	(7.05)
s_2w_2	7.32	10.02	21.43	27.10
	(2.71)	(3.17)	(4.63)	(5.21)
s_2w_3	68.91	72.26	78.65	65.41
	(8.30)	(8.50)	(8.87)	(8.09)
s_2w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_2w_5	81.03	123.11	203.84	190.56
	(9.00)	(11.10)	(14.28)	(13.80)
s_3w_1	10.74	26.61	70.88	58.11
	(3.28)	(5.16)	(8.42)	(7.62)
s_3w_2	8.58	12.06	33.45	36.79
	(2.93)	(3.47)	(5.78)	(6.07)
s_3w_3	78.55	83.64	89.94	75.57
	(8.86)	(9.15)	(9.48)	(8.69)
s_3w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_3w_5	89.98	166.47	245.10	223.36
	(9.49)	(12.90)	(15.66)	(14.95)
SE	0.08	0.08	0.12	0.13
CD at 5%	NS	0.224	0.339	NS

¶ - Transformed values are given in parenthesis

Table 21a. Main effect of spacing and weed management practices on absolute density of grasses, number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	22.17	33.13	41.54	42.90
	(4.71)	(5.76)	(6.45)	(6.55)
S_2	20.57	27.55	37.56	38.40
	(4.54)	(5.25)	(6.13)	(6.20)
S_3	23.07	34.82	46.14	45.81
	(4.80)	(5.90)	(6.79)	(6.77)
SE	0.04	0.03	0.05	0.07
CD at 5%	0.115	0.101	0.158	0.210
Weed management practices				
W_1	6.33	12.06	25.04	23.35
	(2.52)	(3.47)	(5.00)	(4.83)
W_2	5.194	7.99	7.12	13.97
	(2.28)	(2.83)	(2.67)	(3.74)
W_3	46.08	42.85	32.90	27.14
	(6.79)	(6.55)	(5.74)	(5.21)
W_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
W_5	51.07	94.04	154.16	148.40
	(7.15)	(9.70)	(12.42)	(12.19)
SE	0.05	0.04	0.06	0.08
CD at 5%	0.133	0.117	0.183	0.242

¶ - Transformed values are given in parenthesis

Table 21b. Interaction effect of spacing and weed management practices on absolute density of grasses, number m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	6.35	12.36	25.15	23.11
	(2.52)	(3.52)	(5.02)	(4.81)
s_1w_2	5.24	8.15	7.08	13.99
	(2.29)	(2.86)	(2.66)	(3.74)
s_1w_3	46.76	43.33	32.87	28.34
	(6.84)	(6.58)	(5.73)	(5.32)
s_1w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_1w_5	51.66	101.42	153.03	152.02
	(7.19)	(10.07)	(12.37)	(12.33)
s_2w_1	5.65	11.20	22.46	21.92
	(2.38)	(3.35)	(4.74)	(4.68)
s_2w_2	4.78	7.37	5.88	11.69
	(2.19)	(2.72)	(2.43)	(3.42)
s_2w_3	43.04	39.90	30.30	25.87
	(6.56)	(6.32)	(5.50)	(5.09)
s_2w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_2w_5	49.26	74.26	140.33	134.62
	(7.02)	(8.62)	(11.85)	(11.60)
s_3w_1	7.04	12.65	27.63	25.07
	(2.65)	(3.56)	(5.26)	(5.01)
s_3w_2	5.57	8.45	8.49	16.43
	(2.36)	(2.91)	(2.91)	(4.05)
s_3w_3	48.52	45.42	35.63	29.15
	(6.97)	(6.74)	(5.97)	(5.40)
s_3w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_3w_5	52.32	108.20	169.82	159.13
	(7.23)	(10.40)	(13.03)	(12.61)
SE	0.08	0.07	0.11	0.14
CD at 5%	NS	0.202	0.317	NS

¶ - Transformed values are given in parenthesis

The interaction between spacing and weed management was significant at 40 and 60 DAT with s_2w_2, s_1w_2 and s_3w_2 comparable among themselves and significantly superior to all other interactions.

4.2.4.3 Absolute Density of Sedges

The different spacings and weed management practices influenced absolute density of sedges at all stages of observation with the closest spacing (S_3) recording the highest density and it was significantly inferior to rest of treatments (Tables 22a and 22b). At 20 DAT, the widest spacing (S_1) and medium spacing (S_2) were on par. This trend can be seen at harvest too where treatment S_3 was comparable with S_1. The effect of weed management practices on absolute density of sedges was similar to that of total absolute weed density. Only at 40 DAT, S x W interaction was significant with interactions involving W_4 comparable among themselves and significantly superior to all other interactions. These combinations were followed by s_2w_2, s_1w_2 and s_3w_2, which were on par. s_3w_5, was found to be the least effective combination.

4.2.4.4 Absolute Density of Broad Leaved Weeds

Absolute density of broad leaved weeds was significantly influenced by the spacing and weed management practices (Tables 23a and 23b). At 20, 40 and 60 DAT, the medium spacing (S_2) was significantly superior to all other treatments. While at 20 DAT, the widest spacing (S_1) was comparable with S_3; at harvest S_1 was comparable with S_2 in reducing the absolute density of broad leaved weeds. The effect of different weed management practices adopted on absolute density of broad leaved weeds followed the same trend as that of grasses, sedges and all types of weeds together.

4.2.5 Absolute Frequency

4.2.5.1 Total Absolute Weed Frequency

As depicted in Table 24, total absolute weed frequency ranged from 0 in interactions involving W_4 (weed free check) to 300 in interactions involving W_5

Table 22a. Main effect of spacing and weed management practices on absolute density of sedges, number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	6.54 (2.56)	10.56 (3.25)	24.76 (4.98)	6.82 (2.61)
S_2	6.19 (2.49)	9.44 (3.07)	22.54 (4.75)	6.19 (2.49)
S_3	7.20 (2.69)	11.78 (3.43)	26.66 (5.16)	7.96 (2.82)
SE	0.03	0.04	0.05	0.09
CD at 5%	0.100	0.116	0.158	0.252
Weed management practices				
W_1	1.70 (1.30)	5.17 (2.27)	24.18 (4.92)	5.76 (2.40)
W_2	1.37 (1.17)	1.56 (1.25)	14.40 (3.80)	2.26 (1.50)
W_3	14.29 (3.78)	18.65 (4.32)	26.98 (5.19)	8.37 (2.89)
W_4	0.00 (-)	0.00 (-)	0.00 (-)	0.00 (-)
W_5	16.43 (4.05)	26.67 (5.16)	35.34 (5.95)	14.17 (3.76)
SE	0.04	0.05	0.06	0.10
CD at 5%	0.116	0.134	0.183	0.291

¶ - Transformed values are given in parenthesis

Table 22b. Interaction effect of spacing and weed management practices on absolute density of sedges, number m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	1.64	5.59	23.68	5.65
	(1.28)	(2.36)	(4.87)	(2.38)
s_1w_2	1.37	1.47	14.95	2.13
	(1.17)	(1.21)	(3.87)	(1.46)
s_1w_3	14.56	18.60	26.66	8.34
	(3.82)	(4.31)	(5.16)	(2.89)
s_1w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_1w_5	15.72	26.06	36.12	13.87
	(3.96)	(5.11)	(6.01)	(3.73)
s_2w_1	1.60	3.42	23.63	4.92
	(1.27)	(1.85)	(4.86)	(2.22)
s_2w_2	1.23	1.39	11.20	2.06
	(1.11)	(1.18)	(3.35)	(1.44)
s_2w_3	13.47	18.26	25.77	7.43
	(3.67)	(4.27)	(5.08)	(2.73)
s_2w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_2w_5	15.24	24.88	32.59	12.73
	(3.90)	(4.99)	(5.71)	(3.57)
s_3w_1	1.85	6.80	25.23	6.77
	(1.36)	(2.61)	(5.02)	(2.60)
s_3w_2	1.52	1.83	17.42	2.61
	(1.23)	(1.35)	(4.17)	(1.62)
s_3w_3	14.87	19.08	28.52	9.43
	(3.86)	(4.37)	(5.34)	(3.07)
s_3w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_3w_5	18.42	29.17	37.42	16.00
	(4.29)	(5.40)	(6.12)	(4.00)
SE	0.07	0.08	0.11	0.17
CD at 5%	NS	0.233	NS	NS

¶ - Transformed values are given in parenthesis

Table 23a. Main effect of spacing and weed management practices on absolute density of broad leaved weeds, number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	6.94	10.32	18.96	27.96
	(2.63)	(3.21)	(4.35)	(5.29)
S_2	6.23	9.01	16.54	26.65
	(2.50)	(3.00)	(4.07)	(5.16)
S_3	7.35	11.83	20.68	31.20
	(2.71)	(3.44)	(4.55)	(5.59)
SE	0.03	0.06	0.06	0.05
CD at 5%	0.078	0.168	0.170	0.133
Weed management practices				
W_1	1.70	6.20	16.88	24.33
	(1.31)	(2.49)	(4.11)	(4.93)
W_2	1.39	1.46	5.76	15.06
	(1.18)	(1.21)	(2.40)	(3.88)
W_3	13.97	16.40	24.13	34.19
	(3.74)	(4.05)	(4.91)	(5.85)
W_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
W_5	17.94	26.25	34.48	45.16
	(4.24)	(5.12)	(5.87)	(6.72)
SE	0.031	0.07	0.07	0.05
CD at 5%	0.091	0.194	0.196	0.154

¶ - Transformed values are given in parenthesis

Table 23b. Interaction effect of spacing and weed management practices on absolute density of broad leaved weeds, number m^{-2}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	1.69	6.57	17.61	24.07
	(1.30)	(2.56)	(4.20)	(4.91)
s_1w_2	1.38	1.38	5.75	14.37
	(1.17)	(1.18)	(2.40)	(3.79)
s_1w_3	14.49	16.20	24.18	33.61
	(3.81)	(4.02)	(4.92)	(5.70)
s_1w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_1w_5	18.12	25.86	34.87	44.36
	(4.26)	(5.09)	(5.91)	(6.66)
s_2w_1	1.59	5.05	15.12	22.88
	(1.26)	(2.25)	(3.89)	(4.78)
s_2w_2	1.30	1.26	4.30	13.26
	(1.14)	(1.12)	(2.07)	(3.64)
s_2w_3	12.36	14.05	22.54	32.04
	(3.52)	(3.75)	(4.75)	(5.66)
s_2w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_2w_5	16.50	23.91	30.90	43.07
	(4.06)	(4.89)	(5.56)	(6.56)
s_3w_1	1.83	7.07	17.99	26.11
	(1.35)	(2.66)	(4.24)	(5.11)
s_3w_2	1.48	1.78	7.44	17.74
	(1.22)	(1.33)	(2.73)	(4.21)
s_3w_3	15.14	19.13	25.73	36.98
	(3.89)	(4.37)	(5.07)	(6.08)
s_3w_4	0.00	0.00	0.00	0.00
	(-)	(-)	(-)	(-)
s_3w_5	19.24	29.10	37.83	48.15
	(4.39)	(5.39)	(6.15)	(6.94)
SE	0.05	0.11	0.11	0.09
CD at 5%	NS	NS	NS	NS

¶ - Transformed values are given in parenthesis

Table 24. Effect of spacing and weed management practices on total absolute weed frequency#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	166.66	266.67	300.00	300.00
s_1w_2	166.66	166.66	233.34	233.33
s_1w_3	300.00	300.00	300.00	300.00
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	300.00	300.00	300.00	300.00
s_2w_1	166.66	266.67	300.00	300.00
s_2w_2	166.66	166.66	233.34	233.33
s_2w_3	300.00	300.00	300.00	300.00
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	300.00	300.00	300.00	300.00
s_3w_1	166.66	266.67	300.00	300.00
s_3w_2	166.66	166.66	233.34	233.33
s_3w_3	300.00	300.00	300.00	300.00
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	300.00	300.00	300.00	300.00

Worked out mean values

Table 25. Effect of spacing and weed management practices on absolute frequency of grasses#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	100.00	100.00	100.00	100.00
s_1w_2	100.00	100.00	100.00	100.00
s_1w_3	100.00	100.00	100.00	100.00
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	100.00	100.00	100.00	100.00
s_2w_1	100.00	100.00	100.00	100.00
s_2w_2	100.00	100.00	100.00	100.00
s_2w_3	100.00	100.00	100.00	100.00
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	100.00	100.00	100.00	100.00
s_3w_1	100.00	100.00	100.00	100.00
s_3w_2	100.00	100.00	100.00	100.00
s_3w_3	100.00	100.00	100.00	100.00
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	100.00	100.00	100.00	100.00

Worked out mean values

(unweeded control). At all stages of observation, interactions involving W_2 (anilofos +2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) recorded values closer to W_4, which indicates the superiority of this treatment over others.

4.2.5.2 Absolute Frequency of Grasses

At all stages of observation, all interactions recorded the maximum value except s_1w_4, s_2w_4, and s_3w_4 i.e. interactions involving weed free check (W_4), which recorded the lowest value (Table 25).

4.2.5.3 Absolute Frequency of Sedges

Interactions s_1w_3, s_2w_3, and s_3w_3 i.e. interactions involving hand weeding twice (W_3) and s_1w_5, s_2w_5, and s_3w_5 i.e. interactions involving unweeded control (W_5) recorded the highest absolute frequency of sedges through out the observation (Table 26). At 20 DAT, s_1w_2, s_2w_2, and s_3w_2 i.e. all interactions involving W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) and s_1w_1, s_2w_1, and s_3w_1 i.e. all interactions involving W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) recorded the same absolute frequency. But at 40 and 60 DAT, absolute frequencies of sedges in s_1w_2, s_2w_2, and s_3w_2 were lower than that in s_1w_1, s_2w_1, and s_3w_1. At harvest, interactions involving both W_1 and W_2 were similar to interactions involving unweeded control (W_5).

4.2.5.4 Absolute Frequency of Broad Leaved Weeds

Data summarised in Table 27 shows that absolute frequency of broad leaved weeds followed the same trend as that of sedges with the exception that at harvest, even when interactions involving W_1 were similar to interactions involving unweeded control (W_5), interactions involving W_2 continued to record lower values.

Table 26. Effect of spacing and weed management practices on absolute frequency of sedges#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	33.33	100.00	100.00	100.00
s_1w_2	33.33	33.33	66.67	100.00
s_1w_3	100.00	100.00	100.00	100.00
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	100.00	100.00	100.00	100.00
s_2w_1	33.33	100.00	100.00	100.00
s_2w_2	33.33	33.33	66.67	100.00
s_2w_3	100.00	100.00	100.00	100.00
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	100.00	100.00	100.00	100.00
s_3w_1	33.33	100.00	100.00	100.00
s_3w_2	33.33	33.33	66.67	100
s_3w_3	100.00	100.00	100.00	100.00
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	100.00	100.00	100.00	100.00

Worked out mean values

Table 27. Effect of spacing and weed management practices on absolute frequency of broad leaved weeds#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	33.33	66.67	100.00	100.00
s_1w_2	33.33	33.33	66.67	33.33
s_1w_3	100.00	100.00	100.00	100.00
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	100.00	100.00	100.00	100.00
s_2w_1	33.33	66.67	100.00	100.00
s_2w_2	33.33	33.33	66.67	33.33
s_2w_3	100.00	100.00	100.00	100.00
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	100.00	100.00	100.00	100.00
s_3w_1	33.33	66.67	100.00	100.00
s_3w_2	33.33	33.33	66.67	33.33
s_3w_3	100.00	100.00	100.00	100.00
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	100.00	100.00	100.00	100.00

Worked out mean values

4.2.6 Relative Density

The worked out mean relative density values of grasses, sedges and broad leaved weeds are presented in Tables 28, 29 and 30. The data shows higher absolute density for grasses.

4.2.7 Relative Frequency

Tables 31, 32 and 33 depict worked out mean relative frequency values of grasses, sedges and broad leaved weeds. The data shows higher relative frequency for grasses.

4.2.8 Summed Dominance Ratio (SDR)

Mean summed dominance ratio of grasses, sedges and broad leaved weeds are presented in Tables 34, 35 and 36.

4.2.9 Importance Value (IV)

Mean importance values of grasses, sedges and broad leaved weeds are presented in Tables 37, 38 and 39.

4.3 CHEMICAL ANALYSIS

4.3.1 Nutrient Content of Crop

4.3.1.1 Nitrogen Content of Crop

The data presented in Tables 40a and 40b reveal that the nitrogen content of closest spaced treatment (S_3) was significantly higher than other treatments at all stages of observation. The widest spacing (S_1) recorded the lowest values, which was significantly inferior to all other treatments.

The treatment that was kept weed free throughout the entire crop period (W_4) was significantly superior to all other treatments at all stages of observation. This treatment was closely followed by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT), which except at 40 DAT was significantly superior to W_1, W_3 and W_5. At 40 DAT, W_2 was on par with W_1.

Table 28. Effect of spacing and weed management practices on relative density of grasses#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	65.40	50.30	37.84	43.79
s_1w_2	65.60	74.01	25.38	45.66
s_1w_3	61.67	55.44	39.24	40.31
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	60.42	66.12	68.28	72.25
s_2w_1	63.85	56.91	36.68	44.12
s_2w_2	65.26	73.57	27.52	43.09
s_2w_3	62.47	55.23	38.55	39.54
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	60.82	60.33	68.85	70.65
s_3w_1	65.43	47.58	38.97	43.29
s_3w_2	65.01	70.03	25.53	44.65
s_3w_3	61.78	54.30	39.63	38.58
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	58.15	65.00	69.29	71.25

Worked out mean values

Table 29. Effect of spacing and weed management practices on relative density of sedges#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	17.12	22.80	35.67	10.69
s_1w_2	17.15	13.42	53.57	7.13
s_1w_3	19.20	23.80	31.87	11.89
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	18.37	17.00	16.14	6.66
s_2w_1	18.21	17.38	38.62	9.88
s_2w_2	16.86	13.90	52.29	7.85
s_2w_3	19.59	25.30	32.77	11.45
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	18.80	20.22	15.99	6.75
s_3w_1	17.40	25.67	35.66	11.75
s_3w_2	17.74	15.21	52.05	7.15
s_3w_3	18.94	22.83	31.75	12.48
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	20.46	17.52	15.27	7.18

Worked out mean values

Table 30. Effect of spacing and weed management practices on relative density of broad leaved weeds#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	17.49	26.89	26.48	45.52
s_1w_2	17.26	12.57	21.05	47.21
s_1w_3	19.12	20.76	28.89	47.80
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	21.20	16.88	15.58	21.09
s_2w_1	17.94	25.71	24.70	46.00
s_2w_2	17.88	12.53	20.19	49.06
s_2w_3	17.94	19.47	28.68	49.02
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	20.38	19.45	15.16	22.60
s_3w_1	17.17	26.75	25.37	44.96
s_3w_2	17.25	14.76	22.42	48.20
s_3w_3	19.28	22.87	28.62	48.94
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	21.39	17.48	15.44	21.57

Worked out mean values

Table 31. Effect of spacing and weed management practices on relative frequency of grasses#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	60.00	37.50	33.33	33.33
s_1w_2	60.00	60.00	42.86	42.86
s_1w_3	33.33	33.33	33.33	33.33
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	33.33	33.33	33.33	33.33
s_2w_1	60.00	37.50	33.33	33.33
s_2w_2	60.00	60.00	42.86	42.86
s_2w_3	33.33	33.33	33.33	33.33
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	33.33	33.33	33.33	33.33
s_3w_1	60.00	37.50	33.33	33.33
s_3w_2	60.00	60.00	42.86	42.86
s_3w_3	33.33	33.33	33.33	33.33
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	33.33	33.33	33.33	33.33

Worked out mean values

Table 32. Effect of spacing and weed management practices on relative frequency of sedges#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	20.00	37.50	33.33	33.33
s_1w_2	20.00	20.00	28.57	42.86
s_1w_3	33.33	33.33	33.33	33.33
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	33.33	33.33	33.33	33.33
s_2w_1	20.00	37.50	33.33	33.33
s_2w_2	20.00	20.00	28.57	42.86
s_2w_3	33.33	33.33	33.33	33.33
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	33.33	33.33	33.33	33.33
s_3w_1	20.00	37.50	33.33	33.33
s_3w_2	20.00	20.00	28.57	42.86
s_3w_3	33.33	33.33	33.33	33.33
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	33.33	33.33	33.33	33.33

Worked out mean values

Table 33. Effect of spacing and weed management practices on relative frequency of broad leaved weeds#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	20.00	25.00	33.33	33.33
s_1w_2	20.00	20.00	28.57	14.28
s_1w_3	33.33	33.33	33.33	33.33
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	33.33	33.33	33.33	33.33
s_2w_1	20.00	25.00	33.33	33.33
s_2w_2	20.00	20.00	28.57	14.28
s_2w_3	33.33	33.33	33.33	33.33
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	33.33	33.33	33.33	33.33
s_3w_1	20.00	25.00	33.33	33.33
s_3w_2	20.00	20.00	28.57	14.28
s_3w_3	33.33	33.33	33.33	33.33
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	33.33	33.33	33.33	33.33

Worked out mean values

Table 34. Effect of spacing and weed management practices on summed dominance ratio of grasses#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	62.70	43.90	35.59	38.56
s_1w_2	62.80	67.00	34.12	44.26
s_1w_3	47.50	44.38	36.29	36.82
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	46.88	49.73	50.81	52.79
s_2w_1	61.93	47.20	35.01	38.72
s_2w_2	62.63	66.79	35.19	42.97
s_2w_3	47.90	44.28	35.94	36.44
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	47.08	46.83	51.09	51.99
s_3w_1	62.72	42.54	36.15	38.31
s_3w_2	62.50	65.02	34.19	43.75
s_3w_3	47.56	43.82	36.48	35.96
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	45.74	49.16	51.31	52.29

Worked out mean values

Table 35. Effect of spacing and weed management practices on summed dominance ratio of sedges#

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	18.56	30.15	34.50	22.01
s_1w_2	18.57	16.71	41.07	24.99
s_1w_3	26.27	28.57	32.60	22.61
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	25.85	25.17	24.74	20.00
s_2w_1	19.10	27.44	35.98	21.61
s_2w_2	18.43	16.95	40.43	25.36
s_2w_3	26.46	29.31	33.05	22.39
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	26.07	26.77	24.66	20.04
s_3w_1	18.70	31.58	34.50	22.54
s_3w_2	18.87	17.60	40.31	25.00
s_3w_3	26.13	28.08	32.54	22.91
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	26.90	25.43	24.30	20.26

Worked out mean values

Table 36. Effect of spacing and weed management practices on summed dominance ratio of broad leaved weeds[#]

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	18.74	25.95	29.91	39.43
s_1w_2	18.63	16.28	24.81	30.75
s_1w_3	26.23	27.05	31.11	40.56
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	27.27	25.11	24.46	27.21
s_2w_1	18.97	25.36	29.02	39.67
s_2w_2	18.94	16.26	24.38	31.67
s_2w_3	25.64	26.40	31.01	41.17
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	26.86	26.39	24.25	27.97
s_3w_1	18.58	25.88	29.35	39.15
s_3w_2	18.62	17.38	25.49	31.24
s_3w_3	26.31	28.10	30.97	41.14
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	27.36	25.41	24.39	27.45

[#] Worked out mean values

Table 37. Effect of spacing and weed management practices on importance value of grasses[#]

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	37.75	56.38	38.98	37.52
s_1w_2	33.62	52.82	63.48	66.46
s_1w_3	79.53	49.59	47.51	44.39
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	79.78	73.39	66.82	64.96
s_2w_1	35.14	55.76	40.03	39.54
s_2w_2	32.28	53.81	64.25	67.49
s_2w_3	81.01	46.72	46.62	44.87
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	79.15	73.32	67.37	63.65
s_3w_1	34.05	55.10	39.62	38.98
s_3w_2	32.67	54.00	63.53	66.49
s_3w_3	80.05	49.05	47.61	44.97
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	78.30	72.92	67.21	63.27

[#] Worked out mean values

Tablo 38. Effect of spacing and weed management practices on importance value of sedges[#]

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	39.01	33.48	43.82	35.95
s_1w_2	38.70	28.50	17.61	15.09
s_1w_3	13.60	41.26	32.37	29.68
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	12.93	20.92	19.39	19.52
s_2w_1	40.73	32.80	42.91	35.69
s_2w_2	39.87	28.16	16.69	14.11
s_2w_3	12.07	44.61	32.75	30.53
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	13.49	21.96	18.94	20.55
s_3w_1	41.79	33.88	42.46	35.24
s_3w_2	39.55	28.00	16.69	14.57
s_3w_3	13.15	41.34	32.13	31.93
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	14.69	22.00	18.79	20.95

[#] Worked out mean values

Table 39. Effect of spacing and weed management practices on importance value of broad leaved weeds[#]

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	23.24	10.14	17.20	26.53
s_1w_2	27.68	18.68	18.91	18.45
s_1w_3	6.87	9.15	20.12	25.93
s_1w_4	0.00	0.00	0.00	0.00
s_1w_5	7.29	5.69	13.78	15.51
s_2w_1	24.13	11.43	17.06	24.77
s_2w_2	27.85	18.03	19.06	18.40
s_2w_3	6.92	8.67	20.63	24.60
s_2w_4	0.00	0.00	0.00	0.00
s_2w_5	7.35	4.72	13.70	15.80
s_3w_1	24.16	11.01	17.92	25.78
s_3w_2	27.78	18.00	19.78	18.94
s_3w_3	6.80	9.61	20.26	23.10
s_3w_4	0.00	0.00	0.00	0.00
s_3w_5	7.00	5.08	14.00	15.77

[#] Worked out mean values

Table 40a. Effect of spacing and weed management practices on nitrogen content of crop, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	1.62	1.42	1.51	1.41
S_2	1.64	1.49	1.53	1.43
S_3	1.652	1.55	1.54	1.45
SE	0.01	0.01	0.01	0.01
CD at 5%	0.007	0.018	0.012	0.010
Weed management practices				
W_1	1.68	1.52	1.56	1.44
W_2	1.70	1.53	1.58	1.47
W_3	1.65	1.44	1.48	1.42
W_4	1.79	1.56	1.77	1.49
W_5	1.36	1.36	1.25	1.35
SE	0.01	0.01	0.01	0.01
CD at 5%	0.010	0.023	0.015	0.013

Table 40b. Interaction effect of spacing and weed management practices on nitrogen content of crop, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	1.67	1.46	1.54	1.43
s_1w_2	1.69	1.48	1.56	1.44
s_1w_3	1.63	1.40	1.44	1.40
s_1w_4	1.76	1.45	1.76	1.46
s_1w_5	1.34	1.28	1.24	1.32
s_2w_1	1.68	1.52	1.56	1.44
s_2w_2	1.69	1.53	1.58	1.47
s_2w_3	1.65	1.45	1.49	1.41
s_2w_4	1.79	1.57	1.76	1.49
s_2w_5	1.37	1.36	1.26	1.34
s_3w_1	1.69	1.57	1.58	1.45
s_3w_2	1.71	1.59	1.59	1.48
s_3w_3	1.67	1.48	1.50	1.43
s_3w_4	1.82	1.65	1.77	1.50
s_3w_5	1.38	1.45	1.26	1.38
SE	0.01	0.01	0.01	0.01
CD at 5%	0.017	0.018	0.026	0.022

The unweeded control (W_5) recorded the lowest nitrogen content at all stages of observation and it was significantly inferior to all other treatments.

Only at 40 DAT, S x W interaction was significant with s_3w_4 registering significantly higher values than all other interactions. Treatment combinations s_2w_2, s_2w_4 and s_3w_1 were on par while interaction s_1w_5 recorded the lowest nitrogen content, which was significantly inferior to all other interactions.

4.3.1.2 Phosphorus Content of Crop

The closest spacing (S_3) recorded the highest phosphorus content at all stages and it was superior to all other treatments at 20 DAT and at 40 DAT (Tables 41a and 41b). Except at harvest, the medium spacing (S_2) was on par with widest spacing (S_1). At 20 DAT and at harvest, the phosphorus content of widest spacing (S_1) was significantly inferior to all other treatments.

Among weed management practices, weed free treatment (W_4) recorded significantly higher values at all stages of observation and the unweeded treatment (W_5) was significantly inferior to all other treatments. The phosphorus content of W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was significantly superior to both W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) and W_3 (hand weeding twice). Interaction between spacing (S) and weed management practices (W) was insignificant at all stages of observation.

4.3.1.3 Potassium Content of Crop

The widest spacing (S_1) recorded very low potassium content which was significantly inferior to the other two spacings at all growth stages except at harvest (Tables 42a and 42b). The closest spacing (S_3) recorded the highest potassium content at all growth stages. However S_2 (medium spacing) was on par with it at 40 and 60 DAT and at harvest. Except at 60 DAT, W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was significantly superior to both W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) and W_3 (hand weeding twice). But at 60 DAT, W_2 was found to be on

Table 41a. Main effect of spacing and weed management practices on phosphorus content of crop, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	0.83	0.62	0.74	0.71
S_2	0.84	0.62	0.75	0.73
S_3	0.86	0.64	0.76	0.74
SE	0.01	0.01	0.01	0.01
CD at 5%	0.007	0.009	0.007	0.008
Weed management practices				
W_1	0.88	0.63	0.76	0.73
W_2	0.91	0.65	0.79	0.74
W_3	0.74	0.62	0.75	0.71
W_4	0.95	0.68	0.83	0.78
W_5	0.73	0.54	0.62	0.67
SE	0.01	0.01	0.01	0.01
CD at 5%	0.009	0.012	0.010	0.010

Table 41b. Interaction effect of spacing and weed management practices on phosphorus content of crop, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	0.87	0.62	0.75	0.72
s_1w_2	0.90	0.65	0.79	0.73
s_1w_3	0.73	0.61	0.74	0.70
s_1w_4	0.94	0.67	0.82	0.77
s_1w_5	0.72	0.53	0.61	0.66
s_2w_1	0.88	0.63	0.76	0.72
s_2w_2	0.91	0.65	0.79	0.74
s_2w_3	0.74	0.61	0.75	0.71
s_2w_4	0.95	0.67	0.83	0.79
s_2w_5	0.73	0.53	0.62	0.67
s_3w_1	0.90	0.65	0.77	0.74
s_3w_2	0.93	0.66	0.79	0.75
s_3w_3	0.75	0.63	0.76	0.73
s_3w_4	0.96	0.68	0.85	0.79
s_3w_5	0.74	0.54	0.63	0.68
SE	0.01	0.01	0.01	0.01
CD at 5%	NS	NS	NS	NS

Table 42a. Main effect of spacing and weed management practices on potassium content of crop, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	2.22	1.65	1.49	1.31
S_2	2.25	1.67	1.51	1.32
S_3	2.27	1.68	1.52	1.33
SE	0.01	0.01	0.01	0.01
CD at 5%	0.009	0.008	0.011	0.007
Weed management practices				
W_1	2.31	1.72	1.55	1.33
W_2	2.34	1.74	1.56	1.38
W_3	2.16	1.67	1.51	1.30
W_4	2.56	1.78	1.58	1.43
W_5	1.87	1.44	1.34	1.16
SE	0.01	0.01	0.01	0.01
CD at 5%	0.012	0.010	0.014	0.009

Table 42b. Interaction effect of spacing and weed management practices on potassium content of crop, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	2.30	1.71	1.54	1.34
s_1w_2	2.32	1.73	1.55	1.36
s_1w_3	2.13	1.65	1.50	1.30
s_1w_4	2.53	1.76	1.57	1.42
s_1w_5	1.84	1.42	1.31	1.14
s_2w_1	2.30	1.72	1.55	1.32
s_2w_2	2.34	1.74	1.56	1.38
s_2w_3	2.16	1.67	1.51	1.30
s_2w_4	2.56	1.77	1.58	1.43
s_2w_5	1.87	1.44	1.34	1.15
s_3w_1	2.32	1.72	1.55	1.34
s_3w_2	2.36	1.75	1.57	1.39
s_3w_3	2.18	1.69	1.51	1.31
s_3w_4	2.58	1.79	1.59	1.45
s_3w_5	1.89	1.46	1.36	1.17
SE	0.01	0.01	0.01	0.01
CD at 5%	NS	NS	NS	NS

par with W_1 and significantly superior to W_3. At all stages of observation, W_5 (unweeded treatment) recorded significantly inferior values. None of the S x W interactions were significant at any stages of observation.

4.3.2 Nutrient Uptake of Crop

4.3.2.1 Nitrogen Uptake of Crop

The crops grown at closest spacing (S_3) had significantly superior nitrogen uptake at 20 DAT (Tables 43a and 43b). But at all other stages of observation, the medium spacing (S_2) recorded significantly higher values and the closest spacing (S_3) recorded the lowest nitrogen uptake. At 20 and 60 DAT, nitrogen uptake of W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was on par with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) but significantly superior to W_3 (hand weeding twice). At all stages of observation, W_4 (weed free treatment) was significantly superior while nitrogen uptake of W_5 (unweeded treatment) was inferior to all other treatments.

The interaction effect was significant at all stages of observation. At 40 and 60 DAT, s_2w_4 was significantly superior to all other interactions. At 20 DAT, s_3w_4 was significantly superior to all other interactions while s_1w_5 recorded the lowest value. Interactions s_3w_2 and s_3w_1 were comparable among them at 20 DAT. At 40 DAT even though s_1w_5 recorded the lowest value, it was on par with s_3w_5. Interactions s_2w_2, s_2w_1, s_1w_4 and s_1w_2 were comparable among them, At 60 DAT, s_3w_5 was significantly inferior to all other interactions. Nitrogen uptake of s_2w_2 and s_2w_1 were comparable among them. At harvest s_3w_5, which recorded the lowest nitrogen uptake, was on par with s_2w_5. Although s_1w_4 recorded the highest value, it was comparable with s_2w_4, which was on par with s_2w_2.

4.3.2.2 Phosphorus Uptake of Crop

The data presented in Tables 44a and 44b show that closest spacing (S_3) recorded significantly higher values at 20 DAT. The widest spacing (S_1) recorded the least phosphorus uptake at 20 and 60 DAT. This was significantly

Table 43a. Main effect of spacing and weed management practices on nitrogen uptake of crop, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	11.50	57.12	109.29	142.71
S_2	13.04	69.16	135.28	154.06
S_3	17.14	49.69	105.11	130.84
SE	0.10	0.69	1.08	1.50
CD at 5%	0.301	2.012	3.141	4.358
Weed management practices				
W_1	15.44	63.12	125.42	146.34
W_2	15.76	66.94	128.96	157.03
W_3	11.04	50.66	113.37	140.25
W_4	18.63	74.44	146.68	174.20
W_5	8.60	38.11	68.35	94.86
SE	0.13	0.90	1.40	1.94
CD at 5%	0.388	2.597	4.055	5.627

Table 43b. Interaction effect of spacing and weed management practices on nitrogen uptake of crop, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	12.58	63.24	114.07	138.90
s_1w_2	13.23	69.97	116.32	154.13
s_1w_3	9.31	47.25	104.29	129.63
s_1w_4	15.07	72.12	133.19	185.02
s_1w_5	7.29	33.02	78.56	105.88
s_2w_1	14.38	73.04	146.11	164.52
s_2w_2	14.15	74.46	151.01	171.98
s_2w_3	11.10	63.25	138.41	160.55
s_2w_4	16.97	89.45	170.42	179.52
s_2w_5	8.61	45.62	70.46	93.72
s_3w_1	19.36	53.09	116.09	135.60
s_3w_2	19.91	56.40	119.56	144.98
s_3w_3	12.71	41.48	97.41	130.57
s_3w_4	23.85	61.75	136.44	158.06
s_3w_5	9.89	35.70	56.02	84.97
SE	0.23	1.55	2.43	3.36
CD at 5%	0.672	4.498	7.024	9.745

Table 44a. Main effect of spacing and weed management practices on phosphorus uptake of crop, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	5.94	24.95	53.93	72.40
S_2	6.74	29.06	66.26	78.30
S_3	8.96	20.50	57.76	67.14
SE	0.05	0.32	0.57	0.65
CD at 5%	0.139	0.920	1.651	1.888
Weed management practices				
W_1	8.13	26.36	61.31	74.15
W_2	8.50	28.56	64.74	79.37
W_3	4.98	21.62	57.59	70.57
W_4	9.86	32.39	69.02	91.76
W_5	4.59	15.23	33.92	47.22
SE	0.06	0.41	0.74	0.84
CD at 5%	0.180	1.187	2.132	2.437

Table 44b. Interaction effect of spacing and weed management practices on phosphorus uptake of crop, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	6.54	26.88	55.78	70.01
s_1w_2	7.06	30.43	58.99	78.09
s_1w_3	4.18	20.51	53.88	64.30
s_1w_4	8.04	33.21	62.19	96.73
s_1w_5	3.88	13.70	38.79	52.90
s_2w_1	7.53	30.25	71.48	82.86
s_2w_2	7.59	31.68	75.62	86.33
s_2w_3	5.02	26.77	69.53	80.85
s_2w_4	8.96	38.43	79.83	94.63
s_2w_5	4.61	18.17	34.86	46.84
s_3w_1	10.33	21.94	56.69	69.58
s_3w_2	10.84	23.58	59.59	73.71
s_3w_3	5.75	17.59	49.35	66.58
s_3w_4	12.60	25.54	65.05	83.94
s_3w_5	5.28	13.82	28.10	41.91
SE	0.11	0.71	1.27	1.46
CD at 5%	0.311	2.057	3.693	4.221

inferior to all other treatments. At all stages, except at 20 DAT, the medium spacing (S_2) recorded significantly higher values. At 40 DAT and at harvest, the closest spacing (S_3) was significantly inferior to all other treatments. The effect of weed management practices on phosphorus uptake was also significant at all stages of observation. Phosphorus uptake was highest in W_4 (weed free treatment) and it was significantly higher than all other treatments. This was followed by the herbicide treatments (W_2 and W_1) and hand weeding twice (W_3). The minimum phosphorus uptake was observed in unweeded plots (W5).

The interaction effect was significant at all stages of observation with s_1w_5 recording significantly lower values at 20 DAT, which was on par with s_1w_3. Interaction s_3w_4 recorded significantly higher value at this stage. At 40 DAT, s_1w_5, which recorded the lowest value, was comparable with s_3w_5 and both were significantly inferior to all other interactions. Interaction s_2w_2 was comparable with s_1w_4, s_1w_2 and s_2w_1 at 40 DAT. Treatment combination s_2w_4 recorded significantly higher phosphorus uptake at this stage. At 60 DAT and at harvest, s_3w_5 was significantly inferior to all other interactions and recorded the lowest uptake. s_1w_4 and s_2w_4 were comparable at harvest and were significantly superior to all other interactions. s_2w_2, s_3w_4 and s_2w_1 were comparable among themselves at harvest.

4.3.2.3 Potassium Uptake of Crop

Tables 45a and 45b reveal that at 20 DAT, the closest spacing (S_3) was superior to the medium and widest spacing (S_2 and S_1). At all other stages of observation, the medium spacing (S_2) recorded significantly higher potassium uptake compared to S_1 and S_3. The different weed management practices had a significant impact on potassium uptake of crop with weed free treatment (W_4) significantly superior to all other treatments at 20 and 40 DAT and at harvest. At 40 DAT, this treatment was comparable with W_2. Treatment W_2 was comparable with W_1 at 20 and 60 DAT. Both these treatments were superior to hand weeding twice (W_3) at all stages of observation.

Table 45a. Main effect of spacing and weed management practices on potassium uptake of crop, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	15.86	66.98	108.15	132.98
S_2	17.97	77.86	132.24	142.68
S_3	23.64	54.18	102.58	121.32
SE	0.15	0.74	1.13	1.22
CD at 5%	0.432	2.131	3.285	3.528
Weed management practices				
W_1	21.21	71.47	124.45	135.00
W_2	21.73	76.12	127.40	147.61
W_3	14.48	58.77	115.61	129.13
W_4	26.58	85.13	131.24	168.43
W_5	11.77	40.23	72.94	81.45
SE	0.19	0.95	1.46	1.57
CD at 5%	0.558	2.751	4.241	4.555

Table 45b. Interaction effect of spacing and weed management practices on potassium uptake of crop, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	17.34	73.94	114.00	128.27
s_1w_2	18.18	81.39	115.76	145.63
s_1w_3	12.20	55.75	108.70	119.62
s_1w_4	21.63	87.39	119.02	179.62
s_1w_5	9.96	36.44	83.30	91.73
s_2w_1	19.73	82.22	144.95	151.26
s_2w_2	19.54	84.73	148.65	161.28
s_2w_3	14.57	73.10	140.05	147.67
s_2w_4	24.24	101.03	152.54	172.43
s_2w_5	11.75	48.24	75.03	80.76
s_3w_1	26.57	58.24	114.40	125.47
s_3w_2	27.48	62.24	117.81	135.92
s_3w_3	16.66	47.45	98.08	120.11
s_3w_4	33.88	66.96	122.15	153.25
s_3w_5	13.59	36.00	60.49	71.87
SE	0.33	1.65	2.54	2.72
CD at 5%	0.967	4.765	7.346	7.889

The S x W interaction was significant at all stages of observation. At 20 DAT, s_3w_4 recorded significantly higher potassium uptake while s_1w_5 recorded the lowest value. Interactions s_3w_2 and s_3w_1 were comparable among them. At all other stages of observation, s_3w_5 recorded the lowest potassium uptake. At 40 DAT, this interaction was on par with s_1w_5. Interaction s_2w_2 was comparable with s_1w_4, s_2w_1 and s_1w_2. Interaction s_2w_4 was significantly superior to all other treatments. At 60 DAT, also s_2w_4 recorded the highest uptake. But it was on par with s_2w_1. Potassium uptake of s_2w_3 was comparable with s_2w_1 and was significantly superior to all other interactions. At harvest, s_1w_4 recorded the highest potassium uptake and was on par with interaction s_2w_4.

4.3.3 Nutrient Content of Weeds

4.3.3.1 Nitrogen Content of Weeds

None of the different spacings (S) tried influenced nitrogen content of weeds significantly at 20 DAT but at all other stages of observation, the widest spacing (S_1) recorded the highest nitrogen content which was significantly superior to all other treatments (Tables 46a and 46b). The closest spacing (S_3) recorded significantly lower values. The different weed management practices (W) adopted influenced nitrogen content of weeds at all stages of observation with unweeded treatment (W_5) recording significantly higher values. Except at 40 DAT, at all growth stages, the unweeded control (W_5) was followed by hand weeding twice (W_3). Only at 20 DAT, W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was comparable with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) while at all other stages, nitrogen content of W_2 was significantly lower than that of all other treatments.

Only at harvest, there was significant interaction between spacing (S) and weed management practices (W) with s_1w_5, s_2w_5 and s_3w_5 recording significantly higher nitrogen content and these treatments were on par. Interactions involving W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) recorded significantly lower values.

Table 46a. Main effect of spacing and weed management practices on nitrogen content of weeds, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	1.65	1.64	1.87	1.99
S_2	1.64	1.63	1.85	1.98
S_3	1.63	1.62	1.83	1.95
SE	0.01	0.01	0.01	0.01
CD at 5%	NS	0.002	0.018	0.011
Weed management practices				
W_1	1.53	1.75	1.55	1.67
W_2	1.53	1.35	1.45	1.51
W_3	1.73	1.46	2.05	2.14
W_4	-	-	-	-
W_5	1.76	1.94	2.36	2.56
SE	0.01	0.01	0.01	0.01
CD at 5%	0.018	0.018	0.021	0.012

Table 46b. Interaction effect of spacing and weed management practices on nitrogen content of weeds, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
S_1W_1	1.54	1.75	1.56	1.67
S_1W_2	1.54	1.36	1.48	1.54
S_1W_3	1.74	1.47	2.06	2.14
S_1W_4	-	-	-	-
S_1W_5	1.77	1.96	2.38	2.57
S_2W_1	1.53	1.74	1.55	1.67
S_2W_2	1.53	1.36	1.44	1.53
S_2W_3	1.73	1.47	2.05	2.14
S_2W_4	-	-	-	-
S_2W_5	1.76	1.94	2.36	2.56
S_3W_1	1.53	1.74	1.51	1.67
S_3W_2	1.52	1.34	1.43	1.44
S_3W_3	1.72	1.45	2.03	2.13
S_3W_4	-	-	-	-
S_3W_5	1.74	1.93	2.34	2.55
SE	0.01	0.01	0.01	0.01
CD at 5%	NS	NS	NS	0.021

4.3.3.2 Phosphorus Content of Weeds

Weed phosphorus content in widest spacing (S_1) was significantly higher than that of all other treatments at 20 DAT and at harvest while this treatment was comparable with medium spacing (S_2) at 40 and 60 DAT (Tables 47a and 47b). The closest spacing (S_3) recorded significantly lower phosphorus content of weeds at all stages except at 40 DAT and at harvest where it was comparable with S_2. Among the weed management practices, at all stages of observation, the lowest phosphorus content of weeds was recorded by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT), which was significantly superior to all other treatments. But at 40 DAT, phosphorus content of W_2 was comparable with W_1. At all stages of observation, W_5 was significantly inferior to all other treatments. None of the interactions were significant at any period of observation.

4.3.3.3 Potassium Content of Weeds

At all stages of observation, potassium content of weeds in closest spacing (S_3) was significantly lower than the rest of the treatments while widest spacing (S_1) recorded the highest values which was significantly inferior to rest of the treatments (Tables 48a and 48b). Among the weed management practices adopted, W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was significantly superior to all other treatments at all stages of observation while W_5 (unweeded control) recorded the highest content and was significantly inferior to all treatments. At 40 DAT, potassium content of W_3 (hand weeding twice) was on par with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT). None of the interaction effects were significant at any stages of observation.

4.3.4 Nutrient Uptake of Weeds

4.3.4.1 Nitrogen Uptake of Weeds

The different spacings adopted had a significant impact on nitrogen uptake of weeds with widest spacing (S_1) recording the maximum nitrogen uptake,

Table 47a. Main effect of spacing and weed management practices on phosphorus content of weeds, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	0.88	0.71	0.60	0.67
S_2	0.87	0.70	0.59	0.65
S_3	0.86	0.68	0.57	0.64
SE	0.01	0.01	0.01	0.01
CD at 5%	0.008	0.021	0.009	0.012
Weed management practices				
W_1	0.85	0.64	0.55	0.64
W_2	0.83	0.63	0.53	0.62
W_3	0.88	0.68	0.58	0.67
W_4	-	-	-	-
W_5	0.93	0.84	0.68	0.68
SE	0.01	0.01	0.01	0.01
CD at 5%	0.009	0.024	0.010	0.014

Table 47b. Interaction effect of spacing and weed management practices on phosphorus content of weeds, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	0.86	0.66	0.56	0.67
s_1w_2	0.84	0.64	0.55	0.64
s_1w_3	0.89	0.69	0.58	0.68
s_1w_4	-	-	-	-
s_1w_5	0.94	0.86	0.69	0.69
s_2w_1	0.85	0.64	0.56	0.64
s_2w_2	0.83	0.62	0.53	0.61
s_2w_3	0.87	0.69	0.58	0.66
s_2w_4	-	-	-	-
s_2w_5	0.93	0.83	0.69	0.68
s_3w_1	0.84	0.62	0.54	0.62
s_3w_2	0.82	0.62	0.51	0.60
s_3w_3	0.86	0.65	0.57	0.66
s_3w_4	-	-	-	-
s_3w_5	0.92	0.82	0.67	0.67
SE	0.01	0.01	0.01	0.01
CD at 5%	NS	NS	NS	NS

Table 48a. Main effect of spacing and weed management practices on potassium content of weeds, %

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	1.96	1.97	1.67	1.80
S_2	1.94	1.96	1.64	1.77
S_3	1.93	1.94	1.63	1.75
SE	0.01	0.01	0.01	0.01
CD at 5%	0.011	0.009	0.016	0.012
Weed management practices				
W_1	1.93	1.96	1.45	1.85
W_2	1.91	1.93	1.42	1.82
W_3	1.95	1.96	1.47	1.88
W_4	-	-	-	-
W_5	1.98	1.98	2.24	1.54
SE	0.01	0.01	0.01	0.01
CD at 5%	0.012	0.010	0.018	0.014

Table 48b. Interaction effect of spacing and weed management practices on potassium content of weeds, %

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	1.95	1.98	1.46	1.88
s_1w_2	1.93	1.93	1.45	1.84
s_1w_3	1.97	1.99	1.48	1.90
s_1w_4	-	-	-	-
s_1w_5	1.99	1.99	2.28	1.56
s_2w_1	1.93	1.95	1.44	1.84
s_2w_2	1.91	1.93	1.42	1.82
s_2w_3	1.95	1.96	1.48	1.88
s_2w_4	-	-	-	-
s_2w_5	1.99	1.99	2.22	1.55
s_3w_1	1.91	1.93	1.43	1.82
s_3w_2	1.90	1.92	1.40	1.81
s_3w_3	1.94	1.94	1.45	1.86
s_3w_4	-	-	-	-
s_3w_5	1.97	1.96	2.21	1.53
SE	0.01	0.01	0.01	0.01
CD at 5%	NS	NS	NS	NS

which was on par with medium spacing (S_2) at all stages of observation (Tables 49a and 49b). The closest spacing (S_3) registered the lowest uptake values. At all stages of observation, the weed free treatment (W_4) recorded the least nitrogen uptake, which was significantly superior to all other treatments. It was closely followed by W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT), which was significantly superior to W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT). The unweeded treatment (W_5) recorded significantly higher uptake values compared to all other treatments.

The S x W interaction was significant at 40 DAT and at harvest with interactions involving W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) recording significantly lower nitrogen uptake. This set of interaction was significantly superior to all other interactions. Treatment combinations s_1w_2, s_2w_2 and s_3w_2 were on par. At both the stages, s_1w_5 recorded the highest uptake. At 40 DAT, s_1w_5 was significantly inferior to s_2w_5 while at harvest s_1w_5 was on par with s_2w_5.

4.3.4.2 Phosphorus Uptake of Weeds

The data presented in Tables 50a and 50b shows that the closest spacing (S_3) recorded significantly lower value at all the stages of observations. At 40 DAT, the closest spacing (S_3) was comparable with medium spacing (S_2). At harvest, S_1 registered significantly higher uptake values.

The weed free treatment (W_4) was significantly superior to all other treatments. At 20 and 40 DAT, W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was comparable with W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) while at 60 DAT and at harvest; W_2 was significantly superior to W_1. At all stages of observation, W_5 (unweeded control) recorded significantly higher phosphorus uptake values. Only at 40 DAT, the interactions between spacing and weed management practices were significant with interactions s_1w_1, s_2w_1, s_1w_2, s_3w_1, s_2w_2 and s_3w_2 recording lower uptake values. These treatment combinations were comparable among

Table 49a. Main effect of spacing and weed management practices on nitrogen uptake of weeds, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	4.37	8.68	15.05	16.04
S_2	4.28	8.24	14.85	15.60
S_3	3.87	7.77	13.87	14.41
SE	0.12	0.16	0.17	0.17
CD at 5%	0.347	0.465	0.512	0.500
Weed management practices				
W_1	0.86	2.63	5.88	6.91
W_2	0.82	1.67	2.56	2.51
W_3	7.19	6.90	11.51	10.84
W_4	-	-	-	-
W_5	7.83	21.71	38.41	41.14
SE	0.14	0.18	0.20	0.20
CD at 5%	0.400	0.536	0.591	0.577

Table 49b. Interaction effect of spacing and weed management practices on nitrogen uptake of weeds, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	0.89	2.82	6.14	7.33
s_1w_2	0.83	1.93	2.84	2.89
s_1w_3	7.47	6.97	11.92	11.36
s_1w_4	-	-	-	-
s_1w_5	8.29	22.99	39.30	42.58
s_2w_1	0.91	2.59	6.19	7.16
s_2w_2	0.85	1.55	2.62	2.49
s_2w_3	7.36	6.99	11.86	11.00
s_2w_4	-	-	-	-
s_2w_5	8.01	21.82	38.72	41.75
s_3w_1	0.76	2.49	5.33	6.24
s_3w_2	0.76	1.52	2.22	2.15
s_3w_3	6.73	6.74	10.73	10.16
s_3w_4	-	-	-	-
s_3w_5	7.20	20.31	37.19	39.07
SE	0.24	0.32	0.35	0.34
CD at 5%	NS	0.929	NS	0.999

Table 50a. Main effect of spacing and weed management practices on phosphorus uptake of weeds, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	2.29	3.83	4.51	4.81
S_2	2.23	3.56	4.45	4.55
S_3	2.00	3.32	4.09	4.16
SE	0.06	0.09	0.06	0.06
CD at 5%	0.172	0.266	0.190	0.176
Weed management practices				
W_1	0.48	0.97	2.11	2.66
W_2	0.44	0.78	0.94	1.03
W_3	3.63	3.19	3.23	3.38
W_4	-	-	-	-
W_5	4.14	9.35	11.12	10.95
SE	0.07	0.10	0.07	0.07
CD at 5%	0.199	0.307	0.219	0.203

Table 50b. Interaction effect of spacing and weed management practices on phosphorus uptake of weeds, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	0.50	1.05	2.22	2.95
s_1w_2	0.45	0.91	1.05	1.20
s_1w_3	3.82	3.27	3.36	3.62
s_1w_4	-	-	-	-
s_1w_5	4.40	10.07	11.42	11.45
s_2w_1	0.51	0.95	2.22	2.74
s_2w_2	0.47	0.72	0.97	1.00
s_2w_3	3.70	3.27	3.35	3.40
s_2w_4	-	-	-	-
s_2w_5	4.23	9.31	11.27	11.07
s_3w_1	0.42	0.89	1.89	2.30
s_3w_2	0.41	0.70	0.80	0.90
s_3w_3	3.38	3.01	3.00	3.12
s_3w_4	-	-	-	-
s_3w_5	3.78	8.66	10.67	10.33
SE	0.06	0.18	0.13	0.12
CD at 5%	NS	0.532	NS	NS

themselves and significantly superior to s_1w_5, s_2w_5 and s_3w_5, which recorded high phosphorus uptake values.

4.3.4.3 Potassium Uptake of Weeds

The potassium uptake of weeds was lowest in closest spacing (S_3), which was significantly superior to all other treatments at 20 and 60 DAT and at harvest (Tables 51a and 51b). This treatment was comparable with S_2 at 40 DAT. The highest uptake was in S_1, which was on par with S_2 at 20, 40 and 60 DAT. But at harvest, S_1 was significantly inferior to all other treatments. The unweeded treatment (W_5) recorded the highest uptake. W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) was significantly superior to W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) at 60 DAT and at harvest as W_2 recorded lower potassium uptake of weeds. But at 20 and 40 DAT, W_2 was comparable with W_1. None of the interactions were significant at any stages of observation.

4.3.5 Nutrient Status of Soil after Experiment

A perusal the data on organic carbon, available nitrogen, available phosphorus and available potassium (Tables 52a and 52b) reveal that there was significant difference between treatments with closest spacing (S_3) recording the highest nutrient status and it was significantly higher than all other treatments. Among the different weed management practices, the weed free treatment (W_4) recorded the highest nutrient status and it was significantly superior to W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT), W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) and hand weeding twice (W_3) and W_5 (unweeded control). The lowest nutrient status was recorded by W_5, which was significantly inferior to all other treatments. There was no significant interaction between spacing and weed management practices on nutrient status of soil after experiment at any stages of observation.

Table 51a. Main effect of spacing and weed management practices on potassium uptake of weeds, kg ha^{-1}

Treatments	20 DAT	40 DAT	60 DAT	Harvest
Spacing				
S_1	4.99	9.67	13.69	11.89
S_2	4.88	9.19	13.37	11.42
S_3	4.41	8.64	12.50	10.44
SE	0.13	0.19	0.15	0.14
CD at 5%	0.388	0.559	0.453	0.413
Weed management practices				
W_1	1.08	2.94	5.52	7.65
W_2	1.02	2.38	2.52	3.04
W_3	8.11	9.25	8.27	9.52
W_4	-	-	-	-
W_5	8.85	22.10	36.44	24.78
SE	0.15	0.22	0.18	0.16
CD at 5%	0.448	0.646	0.523	0.477

Table 51b. Interaction effect of spacing and weed management practices on potassium uptake of weeds, kg ha^{-1}

Treatment combinations	20 DAT	40 DAT	60 DAT	Harvest
s_1w_1	1.13	3.17	5.75	8.25
s_1w_2	1.04	2.74	2.77	3.45
s_1w_3	8.47	9.39	8.57	10.05
s_1w_4	-	-	-	-
s_1w_5	9.33	23.37	37.67	25.80
s_2w_1	1.14	2.89	5.76	7.89
s_2w_2	1.07	2.22	2.58	2.96
s_2w_3	8.26	9.37	8.57	9.66
s_2w_4	-	-	-	-
s_2w_5	9.07	22.29	36.57	25.15
s_3w_1	0.95	2.76	5.05	6.81
s_3w_2	0.95	2.18	2.18	2.69
s_3w_3	7.59	8.99	7.68	8.84
s_3w_4	-	-	-	-
s_3w_5	8.14	20.63	35.08	23.39
SE	0.26	0.38	0.31	0.28
CD at 5%	NS	NS	NS	NS

Table 52a. Main effect of spacing and weed management practices on nutrient status of soil after experiment

Treatments	Organic carbon, %	N, kg ha^{-1}	P, kg ha^{-1}	K, kg ha^{-1}
Spacing				
S_1	1.51	269.99	23.53	144.77
S_2	1.50	267.21	23.10	144.13
S_3	1.53	275.26	23.99	145.54
SE	0.01	0.95	0.14	0.18
CD at 5%	0.009	2.759	0.412	0.519
Weed management practices				
W_1	1.53	272.59	23.98	144.42
W_2	1.57	282.97	24.87	146.21
W_3	1.48	260.14	22.19	143.32
W_4	1.59	292.23	26.05	148.41
W_5	1.42	246.19	21.00	141.69
SE	0.01	1.23	0.18	0.23
CD at 5%	0.011	3.561	0.531	0.670

Table 52b. Interaction effect of spacing and weed management practices on nutrient status of soil after experiment

Treatment combinations	Organic carbon, %	N, kg ha^{-1}	P, kg ha^{-1}	K, kg ha^{-1}
s_1w_1	1.52	271.70	23.94	144.15
s_1w_2	1.56	283.00	24.95	146.27
s_1w_3	1.48	259.34	22.22	143.23
s_1w_4	1.59	291.09	25.90	148.45
s_1w_5	1.42	244.85	20.62	141.75
s_2w_1	1.51	269.79	23.58	144.02
s_2w_2	1.55	279.91	24.48	145.53
s_2w_3	1.46	254.03	21.82	142.98
s_2w_4	1.58	289.42	25.42	147.49
s_2w_5	1.42	242.89	20.18	140.61
s_3w_1	1.54	276.26	24.42	145.09
s_3w_2	1.57	285.99	25.17	146.82
s_3w_3	1.50	267.06	22.52	143.73
s_3w_4	1.60	296.17	26.83	149.29
s_3w_5	1.43	250.82	20.98	142.74
SE	0.01	2.13	0.32	0.40
CD at 5%	NS	NS	NS	NS

4.4 SHEATH BLIGHT DISEASE INDEX

Closest spacing (S_3) and unweeded treatment (W_5) reported the highest sheath blight disease index and it was significantly higher than all other treatments (Tables 53a and 53b). None of the S x W interactions were significant.

4.5 ECONOMICS

The data summarised in Tables 54a and 54b reveal that the medium spacing of 20 x 10 cm (S_2) and W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) are most remunerative as they recorded higher net income and benefit-cost ratio compared to other treatments. The corresponding values for closest spacing (S_3) and unweeded treatment (W_5) were inferior to all other treatments. Hand weeding twice (W_3) was found to be less remunerative than W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) as it recorded lower net income and benefit-cost ratio. Weed free check (W_4) was the least remunerative treatment and it was inferior to all other treatments although gross return was the highest from this treatment. Among S x W interactions, net income and benefit-cost ratio of s_2w_2 was superior to all other interactions.

4.6 CORRELATION STUDIES

Simple correlations of weed and crop characters with crop grain yield were worked out and the results are presented in Tables 55. The grain yield was found significantly and positively correlated with crop growth characters, crop yield attributes namely number of productive tillers per hill, weight of panicle, number of spikelets per panicle, number of filled grains per panicle, thousand grain weight, straw yield and harvest index. Nutrient (nitrogen, phosphorus and potassium) content and uptake by crop and nutrient status of soil after experiment also showed significant positive correlation with grain yield.

Significant negative correlation was observed with crop yield attributes namely chaff percentage and weed index. Among the weed characters, weed dry

Table 53a. Main effect of spacing and weed management practices on sheath blight disease index

Treatments	Sheath blight disease index
Spacing	
S_1	9.39 (3.06)
S_2	26.68 (5.17)
S_3	58.63 (7.66)
SE	0.12
CD at 5%	0.335
Weed management practices	
W_1	29.20 (5.40)
W_2	23.96 (4.90)
W_3	32.74 (5.72)
W_4	17.92 (4.23)
W_5	38.73 (6.22)
SE	0.15
CD at 5%	0.433

¶ - Transformed values are given in parenthesis

Table 53b. Interaction effect of spacing and weed management practices on sheath blight disease index

Treatment combinations	Sheath blight disease index
s_1w_1	9.64 (3.12)
s_1w_2	8.20 (2.86)
s_1w_3	11.08 (3.33)
s_1w_4	3.27 (1.81)
s_1w_5	17.78 (4.22)
s_2w_1	27.40 (5.23)
s_2w_2	24.41 (4.94)
s_2w_3	28.86 (5.37)
s_2w_4	21.47 (4.63)
s_2w_5	31.84 (5.64)
s_3w_1	61.95 (7.87)
s_3w_2	47.33 (6.88)
s_3w_3	71.66 (8.47)
s_3w_4	39.17 (6.26)
s_3w_5	77.61 (8.81)
SE	0.26
CD at 5%	NS

¶ - Transformed values are given in parenthesis

Table 54a. Main effect of spacing and weed management practices on net income and benefit-cost ratio

Treatments	Net income, Rs ha^{-1}	Benefit-cost ratio
Spacing		
S_1	41853.09	1.36
S_2	52009.15	1.69
S_3	30418.26	0.98
Weed management practices		
W_1	51370.50	1.77
W_2	58208.68	2.07
W_3	45276.93	1.54
W_4	27508.43	0.42
W_5	24769.63	0.93

Table 54b. Interaction effect of spacing and weed management practices on net income and benefit-cost ratio

Treatment combinations	Net income, Rs ha^{-1}	Benefit-cost ratio
s_1w_1	51076.53	1.771
s_1w_2	58021.38	2.074
s_1w_3	45548.17	1.560
s_1w_4	28942.39	0.439
s_1w_5	25677.01	0.966
s_2w_1	63354.74	2.187
s_2w_2	67855.72	2.415
s_2w_3	59561.67	2.030
s_2w_4	35285.25	0.534
s_2w_5	33988.37	1.273
s_3w_1	39680.24	1.353
s_3w_2	48748.94	1.713
s_3w_3	30720.95	1.034
s_3w_4	18297.65	0.275
s_3w_5	14643.50	0.541

Table 55. Simple correlation coefficients of important parameters with crop yield

Sl. No.	Parameters	Grain yield
1	Crop growth characters	
1.1	Plant height	
1.1.1	Plant height at 40 DAT	0.9285**
1.1.2	Plant height at 60 DAT	0.9275**
1.1.3	Plant height at harvest	0.9387**
1.2	Number of tillers per hill	
1.2.1	Number of tillers per hill at 40 DAT	0.9222**
1.2.2	Number of tillers per hill at 60 DAT	0.9077**
1.2.3	Number of tillers per hill at harvest	0.9556**
1.3	Dry matter production	
1.3.1	Dry matter production at 40 DAT	0.9332**
1.3.2	Dry matter production at 60 DAT	0.8892**
1.3.3	Dry matter production at harvest	0.9964**
1.4.	Leaf area index at panicle initiation stage	0.5355*
2	Crop yield attributes	
2.1.	Number of productive tillers per hill	0.9378**
2.2.	Weight of panicle	0.8789**
2.3.	Number of spikelets per panicle	0.9447**
2.4.	Number of filled grains per panicle	0.9574**
2.5.	Chaff percentage	- 0.8571**
2.6.	Thousand grain weight	0.8828**
2.7.	Straw yield	0.9903**
2.8.	Harvest index	0.9572**
2.9.	Weed index	- 0.9327**
3	Observations on weeds	
3.1	Weed dry weight	
3.1.1	Weed dry weight of all type of weeds	
3.1.1.1	Weed dry weight of all type of weeds at 20 DAT	- 0.7037**
3.1.1.2	Weed dry weight of all type of weeds at 40 DAT	- 0.8216**
3.1.1.3	Weed dry weight of all type of weeds at 60 DAT	- 0.8275**
3.1.1.4	Weed dry weight of all type of weeds at harvest	- 0.8221**
3.1.2	Weed dry weight of grasses	
3.1.2.1	Weed dry weight of grasses at 20 DAT	- 0.6887**
3.1.2.2	Weed dry weight of grasses at 40 DAT	- 0.8141**
3.1.2.3	Weed dry weight of grasses at 60 DAT	- 0.8112**
3.1.2.4	Weed dry weight of grasses at harvest	- 0.8045**

** Significant at 0.01 level; * significant at 0.05 level

Contd...

Table 55 continued

Sl. No.	Parameters	Grain yield
3.1.3	Weed dry weight of sedges	
3.1.3.1	Weed dry weight of sedges at 20 DAT	- 0.7474**
3.1.3.2	Weed dry weight of sedges at 40 DAT	- 0.7492**
3.1.3.3	Weed dry weight of sedges at 60 DAT	- 0.7870**
3.1.3.4	Weed dry weight of sedges at harvest	- 0.8124**
3.1.4	Weed dry weight of broad leaved weeds	
3.1.4.1	Weed dry weight of broad leaved weeds at 20 DAT	- 0.6990**
3.1.4.2	Weed dry weight of broad leaved weeds at 40 DAT	- 0.7696**
3.1.4.3	Weed dry weight of broad leaved weeds at 60 DAT	- 0.8308**
3.1.4.4	Weed dry weight of broad leaved weeds at harvest	- 0.8131**
3.2	Weed control efficiency	
3.2.1	Weed control efficiency of all type of weeds	
3.2.1.1	Weed control efficiency of all type of weeds at 20 DAT	0.7276**
3.2.1.2	Weed control efficiency of all type of weeds at 40 DAT	0.8376**
3.2.1.3	Weed control efficiency of all type of weeds at 60 DAT	0.8318**
3.2.1.4	Weed control efficiency of all type of weeds at harvest	0.8314**
3.2.2	Weed control efficiency of grasses	
3.2.2.1	Weed control efficiency of grasses at 20 DAT	0.7122**
3.2.2.2	Weed control efficiency of grasses at 40 DAT	0.8296**
3.2.2.3	Weed control efficiency of grasses at 60 DAT	0.8191**
3.2.2.4	Weed control efficiency of grasses at harvest	0.8182**
3.2.3	Weed control efficiency of sedges	
3.2.3.1	Weed control efficiency of sedges at 20 DAT	0.7543**
3.2.3.2	Weed control efficiency of sedges at 40 DAT	0.7648**
3.2.3.3	Weed control efficiency of sedges at 60 DAT	0.7997**
3.2.3.4	Weed control efficiency of sedges at harvest	0.8220**
3.2.4	Weed control efficiency of broad leaved weeds	
3.2.4.1	Weed control efficiency of broad leaved weeds at 20 DAT	0.7436**
3.2.4.2	Weed control efficiency of broad leaved weeds at 40 DAT	0.7780**
3.2.4.3	Weed control efficiency of broad leaved weeds at 60 DAT	0.8343**
3.2.4.4	Weed control efficiency of broad leaved weeds at harvest	0.8296**
3.3	Absolute density	
3.3.1	Absolute density of all type of weeds	
3.3.1.1	Absolute density of all type of weeds at 20 DAT	- 0.7691**
3.3.1.2	Absolute density of all type of weeds at 40 DAT	- 0.8652**
3.3.1.3	Absolute density of all type of weeds at 60 DAT	- 0.8779**
3.3.1.4	Absolute density of all type of weeds at harvest	- 0.8710**

** Significant at 0.01 level; * significant at 0.05 level

Contd...

Table 55 continued

Sl. No.	Parameters	Grain yield
3.3.2	Absolute density of grasses	
3.3.2.1	Absolute density of grasses at 20 DAT	- 0.7572**
3.3.2.2	Absolute density of grasses at 40 DAT	- 0.8620**
3.3.2.3	Absolute density of grasses at 60 DAT	- 0.8464**
3.3.2.4	Absolute density of grasses at harvest	- 0.8349**
3.3.3	Absolute density of sedges	
3.3.3.1	Absolute density of sedges at 20 DAT	- 0.7681**
3.3.3.2	Absolute density of sedges at 40 DAT	- 0.8317**
3.3.3.3	Absolute density of sedges at 60 DAT	- 0.8024**
3.3.3.4	Absolute density of sedges at harvest	- 0.8617**
3.3.4	Absolute density of broad leaved weeds	
3.3.4.1	Absolute density of broad leaved weeds at 20 DAT	- 0.7953**
3.3.4.2	Absolute density of broad leaved weeds at 40 DAT	- 0.8636**
3.3.4.3	Absolute density of broad leaved weeds at 60 DAT	- 0.8516**
3.3.4.4	Absolute density of broad leaved weeds at harvest	- 0.8385**
4.	Chemical analysis	
4.1	Chemical analysis of crop	
4.1.1	Nutrient content of crop	
4.1.1.1	Nitrogen content of crop	
4.1.1.1.1	Nitrogen content of crop at 20 DAT	0.8072**
4.1.1.1.2	Nitrogen content of crop at 40 DAT	0.3096
4.1.1.1.3	Nitrogen content of crop at 60 DAT	0.8049**
4.1.1.1.4	Nitrogen content of crop at harvest	0.7191**
4.1.1.2	Phosphorus content of crop	
4.1.1.2.1	Phosphorus content of crop at 20 DAT	0.7058**
4.1.1.2.2	Phosphorus content of crop at 40 DAT	0.7538**
4.1.1.2.3	Phosphorus content of crop at 60 DAT	0.8004**
4.1.1.2.4	Phosphorus content of crop at harvest	0.6990**
4.1.1.3	Potassium content of crop	
4.1.1.3.1	Potassium content of crop at 20 DAT	0.8087**
4.1.1.3.2	Potassium content of crop at 40 DAT	0.8028**
4.1.1.3.3	Potassium content of crop at 60 DAT	0.7889**
4.1.1.3.4	Potassium content of crop at harvest	0.8078**
4.1.2	Nutrient uptake of crop	
4.1.2.1	Nitrogen uptake of crop	
4.1.2.1.1	Nitrogen uptake of crop at 20 DAT	0.4637
4.1.2.1.2	Nitrogen uptake of crop at 40 DAT	0.9439**
4.1.2.1.3	Nitrogen uptake of crop at 60 DAT	0.9361**
4.1.2.1.4	Nitrogen uptake of crop at harvest	0.9414**

*** Significant at 0.01 level; * significant at 0.05 level*

Contd...

Table 55 continued

Sl. No.	Parameters	Grain yield
4.1.2.2	Phosphorus uptake of crop	
4.1.2.2.1	Phosphorus uptake of crop at 20 DAT.	0.4461
4.1.2.2.2	Phosphorus uptake of crop at 40 DAT	0.9505**
4.1.2.2.3	Phosphorus uptake of crop at 60 DAT	0.9310**
4.1.2.2.4	Phosphorus uptake of crop at harvest	0.9376**
4.1.2.3	Potassium uptake of crop	
4.1.2.3.1	Potassium uptake of crop at 20 DAT	0.4756
4.1.2.3.2	Potassium uptake of crop at 40 DAT	0.9562**
4.1.2.3.3	Potassium uptake of crop at 60 DAT	0.9170**
4.1.2.3.4	Potassium uptake of crop at harvest	0.9394**
4.2.1	Nutrient content of weeds	
4.2.1.1	Nitrogen content of weeds	
4.2.1.1.1	Nitrogen content of weeds at 20 DAT	- 0.5584*
4.2.1.1.2	Nitrogen content of weeds at 40 DAT	- 0.6288*
4.2.1.1.3	Nitrogen content of weeds at 60 DAT	- 0.7014**
4.2.1.1.4	Nitrogen content of weeds at harvest	- 0.7160**
4.2.1.2	Phosphorus content of weeds	
4.2.1.2.1	Phosphorus content of weeds at 20 DAT	- 0.5414*
4.2.1.2.2	Phosphorus content of weeds at 40 DAT	- 0.6314*
4.2.1.2.3	Phosphorus content of weeds at 60 DAT	- 0.6111*
4.2.1.2.4	Phosphorus content of weeds at harvest	- 0.5233*
4.2.1.3	Potassium content of weeds	
4.2.1.3.1	Potassium content of weeds at 20 DAT	- 0.5018
4.2.1.3.2	Potassium content of weeds at 40 DAT	- 0.4932
4.2.1.3.3	Potassium content of weeds at 60 DAT	- 0.7170**
4.2.1.3.4	Potassium content of weeds at harvest	- 0.3703
4.2.2	Nutrient uptake of weeds	
4.2.2.1	Nitrogen uptake of weeds	
4.2.2.1.1	Nitrogen uptake of weeds at 20 DAT	- 0.7070**
4.2.2.1.2	Nitrogen uptake of weeds at 40 DAT	- 0.8169**
4.2.2.1.3	Nitrogen uptake of weeds at 60 DAT	- 0.8191**
4.2.2.1.4	Nitrogen uptake of weeds at harvest	- 0.8140**
4.2.2.2	Phosphorus uptake of weeds	
4.2.2.2.1	Phosphorus uptake of weeds at 20 DAT	- 0.7157**
4.2.2.2.2	Phosphorus uptake of weeds at 40 DAT	- 0.8104**
4.2.2.2.3	Phosphorus uptake of weeds at 60 DAT	- 0.8171**
4.2.2.2.4	Phosphorus uptake of weeds at harvest	- 0.8179**
4.2.2.3	Potassium uptake of weeds	
4.2.2.3.1	Potassium uptake of weeds at 20 DAT	- 0.7068**
4.2.2.3.2	Potassium uptake of weeds at 40 DAT	- 0.8186**
4.2.2.3.3	Potassium uptake of weeds at 60 DAT	- 0.8101**
4.2.2.3.4	Potassium uptake of weeds at harvest	- 0.8234**

** Significant at 0.01 level; * significant at 0.05 level weight and nutrient uptake by weeds recorded significant negative values, while weed control efficiency recorded significant positive correlation with yield.

DISCUSSION

5 DISCUSSION

Basmati, the scented long rice once cultivated exclusively in specific geographical areas of India and Pakistan is now being successfully cultivated in wetland ecosystems of Kerala. Rice is the most important cereal crop of Kerala grown by marginal and poor farmers. The high cost of labour had made rice cultivation nonremunerative. This forced the traditional rice farmers to try basmati cultivation. Eventhough the yield of basmati rice is comparatively lower than traditional nonscented varieties, the fact that they fetch a premium market price is an incentive to rice farmer to take up basmati cultivation. It was therefore felt necessary to formulate the right plant population and weed management practices for basmati rice so as to increase and sustain the productivity and profitability of the crop. The present investigation is an attempt to find out the impact of plant population and weed management practices on the performance of basmati rice and the results are discussed below.

5.1 OBSERVATIONS ON CROP

5.1.1 Crop Growth Characters

The results revealed that the effect of spacings and weed management practices on crop growth characters were substantial at all stages of crop growth. The medium spacing 20 x 10 cm (S_2), which is the recommended spacing for medium duration rice in the state, was very effective in producing taller plants with higher number of tillers per hill and higher leaf area index thus resulting in higher dry matter production at all stages of observation, except at 20 DAT. At 20 DAT alone, the closest spacing 15 x 10 cm (S_3) with 34 per cent more plant population than S_2, produced the tallest plants probably due to initial competition with rice plants for utilizing available sunlight. This also resulted in significantly higher dry matter production at this spacing at 20 DAT. Nevertheless, during the later stages, the competition between rice plants in closest spacing (S_3) for available sunlight was so high that it resulted in reduced plant height, less number of tillers per hill, lower leaf area index and significantly lower dry matter production. Number of effective tillers per hill was found to be significantly less in the low plant density treatment S_1 (12 per cent less) as compared to recommended density (S_2). However 34 per cent increase in plant density (S_3) could not increase the number of productive tillers, which was significantly lower than that in recommended spacing. Lourduraj (1999) reported that planting geometry has pronounced effect on tillering and interception and utilization of light in rice. Hua *et al.* (2000) opined that light penetration of the canopy decreased as plant spacing decreased.

On the other hand, the widest spacing (S_1) with 12 per cent less plant population than S_2 failed to register significantly superior plant height. This may be because the wide interspaces enabled luxuriant weed growth, which utilized the excess sunlight falling in the interspaces of the crop to smother the rice crop as evident from the higher values recorded for weed dry weight at this spacing. This resulted in reduced number of tillers per hill, lower leaf area index and thus a lower dry matter production in rice transplanted at widest spacing (S_1). Ali and Sankaran (1975) reported that severe weed infestation suppressed the height of rice plants. However Shrirame *et al.* (2000) observed that with decreasing plant density, there was increase in number of functional leaves per hill, maximum leaf area per hill and total number of tillers per hill. Contrary to this, Rajarathinam and Balasubramaniyan (1999) found the dry matter production increasing with increase in number of hills m^{-2} from 25 to 50. Fu *et al.* (2000) had reported that plant height was significantly decreased at narrowest spacing. He also opined that with decreasing plant density, the number of tillers and leaves increased and the growth period was extended.

Weed management using herbicides alone (W_2), wherein pre-emergent anilofos + 2,4-D EE readymix application was followed by post emergent 2,4-D sodium salt application, had a simulative effect on plant height, tillers per hill, leaf area index and dry matter production as evidenced by their significantly higher values. This may be due to its favourable effect in preventing crop-weed competition at critical growth stage of crop as evidenced by reduced density and dry matter accumulation in weeds. The use of herbicides alone for weed control

(W_2) i.e, pre-emergent anilofos + 2,4-D EE readymix application followed by post emergent 2,4-D sodium salt application, was more effective than the use of pre-emergent anilofos + 2,4-D EE readymix application followed by hand weeding (W_1) and hand weeding twice (W_3), in increasing the plant height, tiller number per hill, leaf area index and thus resulted in a higher dry matter production. This could probably be due to the indirect effect of reduced weed density, dry matter production and nutrient uptake by weeds in this treatment.

Leaf area index was the highest in weed free plots. Leaf area index is an important measure of potential photosynthetic area and thus of the growth capability (Potter and Jones, 1997). The unweeded control recorded the lowest leaf area index, which may be attributed to the severe competition between the crop and weeds. Hand weeding twice also recorded reduced leaf area index, which was significantly less than the herbicide treatments. Yang *et al.* (1980) had reported that plant height was a little higher in herbicide treatments than in hand weeded plots. Renjan (1999) and Nair (2001) reported a decrease in leaf area index due to weed competition. Balasubramanian (1996) noticed reduction in plant height and dry matter production due to weed infestation.

Compared to herbicide treatments, where pre-emergent application of anilofos + 2,4-D EE readymix was there, values for growth attributes were lower in plots hand weeded twice (W_3). This could be because manual weeding allowed unchecked weed growth up to 20 DAT (time of first manual weeding), thus causing considerable depletion of resources during the early crop growth. Gupta and Lamba (1978) observed that by manual weeding, weeds were removed after they have put forth considerable competition to crop and rarely at ideal time where as herbicides provided the benefit of timely weed control.

Rice transplanted at 20 x 10 cm spacing and treated with the pre-emergent herbicide anilophos + 2,4-D EE ready mix at 6 DAT followed by 2,4-D sodium salt at 20 DAT (S_2W_2) resulted in enhanced plant height, more number of tillers per hill, higher leaf area index and higher dry matter production compared to other S x W interactions except those interactions involving weed free check.

Mabbayad and Moody (1992) noticed a reduction in tiller number and crop growth rate due to weed competition in rice plants.

5.1.1 Crop Yield Attributes

The different spacings and weed management practices had a marked effect on yield attributing characters such as number of productive tillers per hill, panicle weight, number of spikelets per panicle, filled grains per panicle, chaff percentage, thousand grain weight, grain yield, straw yield, harvest index and weed index. The medium spacing of 20 x 10 cm (S_2) had a significant influence on crop yield attributes compared to rest of the treatments as evidenced by its superior value. The grain yield increased significantly with increase in population up to the recommended level (S_2). Similar positive effect of 20 x 10 cm spacing on the grain yield of basmati rice cv. Basmati 370 has been reported by Padmajarao (1995). On an average, 12 per cent less plant population (S_1) and 34 per cent more population (S_3) produced 12.08 per cent and 24.49 per cent less yield compared to S_2. Bindra and Kalia (2000) also could not increase grain yield by increasing plant population by 33 per cent over normal plant stand of 20 x 10 cm.

Yield attributing characters like number of productive tillers m^{-2} and percentage of filled grains was significantly high in W_2 and it was only next to weed free check (W_4). Yield components determine the final yield. Yield can be limited either by the supply of assimilates (source) during grain filling or by the number and capacity of kernels to be filled (sink) or by source and sink simultaneously (Fischer, 1983; Venkateswaralu and Visperas, 1987; Evans, 1993). In the present study, both source and sink were limited due to weed competition in unweeded control (W_5) resulting in significantly low grain yield in this treatment. Corroboratory results on the significant effect of medium spacing (S_2) with 50 hills m^{-2} on yield parameters like panicles m^{-2}, panicle weight, grains per panicle, filled grains per panicle, thousand grain weight and grain yield were reported in rice hybrid by Rajarathnam and Balasubramaniyan (1999) and Geethadevi *et al.* (2000)

Between the two parameters namely number of panicles per unit area and number of spikelets per panicle, the former is the most important. Zadeh and Mirlohi (1998) explained that on one hand closer spacing leads to more number of tillers per unit area and thus more number of panicles per unit area. On the other hand, there is a decrease in number of tillers per plant and number of spikelets per panicle at closer spacing along with lower harvest index. Thus an indirect effect of panicle number per unit area on yield exists through its association with grain number per panicle, which prevented real effects of grain number per panicle on yield. The maximum yield results when a stable equilibrium is achieved between number of panicles per unit area and number of spikelets per panicle. This resulted in medium spacing (S_2) recording the highest grain yield. Importance of number of panicles per unit area in determining the grain yield was also reported by many investigators (Kyeong *et al.*, 1999; Cruscicol *et al.*, 2000 and Patra and Nayak 2001).

Yield decrease due to adoption of widest spacing of 15 x 15 cm (S_1) compared to medium spacing (S_2) was 12.08 per cent. Corroboratory results were obtained by Lourduraj (1999) who opined that for medium duration rice cultivars, the optimum plant population for achieving maximum yield is 5.0×10^5 hills ha^{-1} (20 x 10 cm). The scented rice cv. Pusa Basmati-1 with growth duration of 135 days falls in the medium duration category. The closest spacing (S_3) recorded a chaff percentage of 18.87 whereas for the best treatments S_1 and S_2, the chaff percentages were only 15.32 and 16.55 respectively. Tuong *et al.* (2000) explained that high plant density of rice resulted in excessive vegetative growth and the resulting inter and intra plant competition and low radiation interception caused high tiller abortion and resulted in lower yield.

Various weed management practices adopted, significantly influenced all the yield attributes. The weed free check (W_4) registered the highest value for all of them. This is evidently because of the weed free environment, which allowed the crop to express its genetic potential in a better way. Weed competition severely reduced the availability of moisture, nutrients and sunlight to the rice crop resulting in lowest value for weedy check (W_5). The use of herbicides and hand weeding for weed management resulted in significantly higher yield attributes compared to weedy check (W_5) thus clearly proving that these practices were effective in reducing the weed competition in rice and thus reduced considerably the ill effects associated with such competition which is manifested in crop yield. Singh and Sharma (1994) also opined that two hand weedings or one pre-emergent herbicide followed by a hand weeding had a significant positive influence on attributing characters of rice. Similar view was expressed by Muntanal *et al.* (1997) and Pandey *et al.* (1997).

The fact that all the yield attributes namely number of productive tillers, panicle weight, number of spikelets per panicle, number of filled grains per panicle, chaff percentage, thousand grain weight, straw yield, harvest index and weed index were significantly and positively influenced by W_2 (anilophos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) resulted in that treatment registering a higher grain yield of 3927.85 kg ha^{-1}. Compared to weed free check (W_4) which recorded 4267.38 kg ha^{-1}, the yield loss was only marginal i.e. 8.65 per cent when W_2 was adopted. But the yield advantage of this treatment over W_1 (anilophos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT), W_3 (hand weeding twice at 20 and 40 DAT) and W_5 (unweeded control) were 7.20, 14.01 and 41.31 per cent respectively. The higher grain and straw yields in weed free treatments and treatments involving herbicides or hand weeding or both can be attributed to higher nutrient uptake, higher weed control efficiency and better availability of moisture and sunlight to the crop.

Hand weeding twice at 20 and 40 DAT (W_3) recorded a yield advantage of 31.75 per cent over the unweeded treatment (W_5) mainly because of higher number of productive tillers per hill (8.36) compared to W_5 (6.86). Balasubramanian (1996) also pointed out that number of productive tillers in rice could be enhanced by hand weeding twice. Other crop yield attributes also contributed significantly in increasing the grain yield of W_3.

Mukhopadhyay (1967) reported the superiority of chemical treatment over hand weeding in weed control. There was no significant difference between W_2 and W_1 on panicle weight, number of spikelets per panicle and chaff percentage.

But the number of productive tillers per hill and thousand grain weight of W_2 were significantly superior. This is due to the better weed management in W_2 compared to W_1. Superiority of combination herbicide (anilofos + 2,4-D) followed by 2,4-D application in controlling weeds was reported earlier by Rao (1995) and Rao and Singh (1997). Singh *et al.* (2000a) also reported that pre-emergence mixture of anilofos + 2,4-D EE followed by one hand weeding resulted in highest grain yield.

Interaction effect between spacing and weed management practices influenced grain and straw yield and weed index. Treatment combination S_2W_2 was comparable with S_1W_4 in increasing the grain yield and straw yield. With regard to weed index S_2W_2 was significantly inferior to S_1W_4, S_2W_4 and S_3W_4 but superior to all other interactions thus proving the influence of medium spacing (S_2) and sequential application of herbicides (W_2) in enhancing rice yield.

5.2 OBSERVATION ON WEEDS

On an average, one *Echinochloa crus-galli* m^{-2} caused an 11 per cent reduction in rice grain yield (Auld and Kim, 1998). Tjitrosemito and Soerianegara (1996) reported that one plant m^{-2} of *Cyperus iria, Ludwigia octovalvis* and *Cyperus difformis* reduced rice grain yield by 62, 49 and 29 kg ha^{-1} respectively. In the present investigation, *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv.. and *Leersia hexandra* S. W. were the most important grassy weeds present. Among sedges, *Cyperus iria* L., *Cyperus difformis* L. and *Fimbristylis miliaceae* (L.) Vahl. were the predominant ones. *Ludwigia parviflora* Roxb. and *Monochoria vaginalis* (Burm. F.) Kunth. were the most problematic broad leaved weeds observed.

Spacing had a pronounced effect in reducing the absolute density of all type of weeds in rice field through out the growth stage of the crop. The closest spacing of 15 x 10 cm (S_3) recorded the highest absolute density of all type of weeds but the least dry weight. This is because the 34 per cent increase in crop stand at the closest spacing compared to the medium spacing (S_2) prevented the sprouted weed seedlings from harvesting adequate sunlight and other resourses,

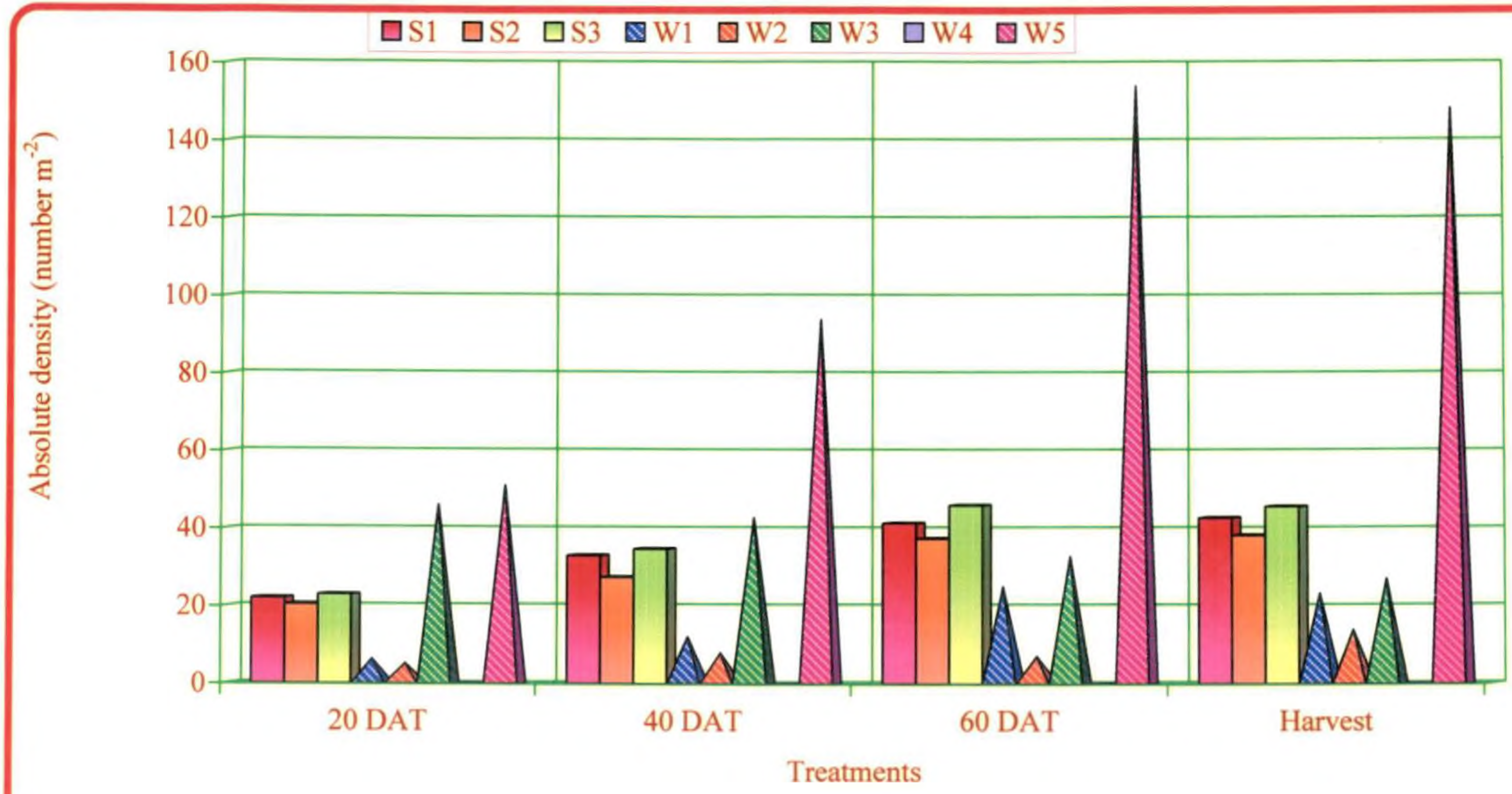


Fig. 3a. Main effect of spacing and weed management practices on absolute density of grasses

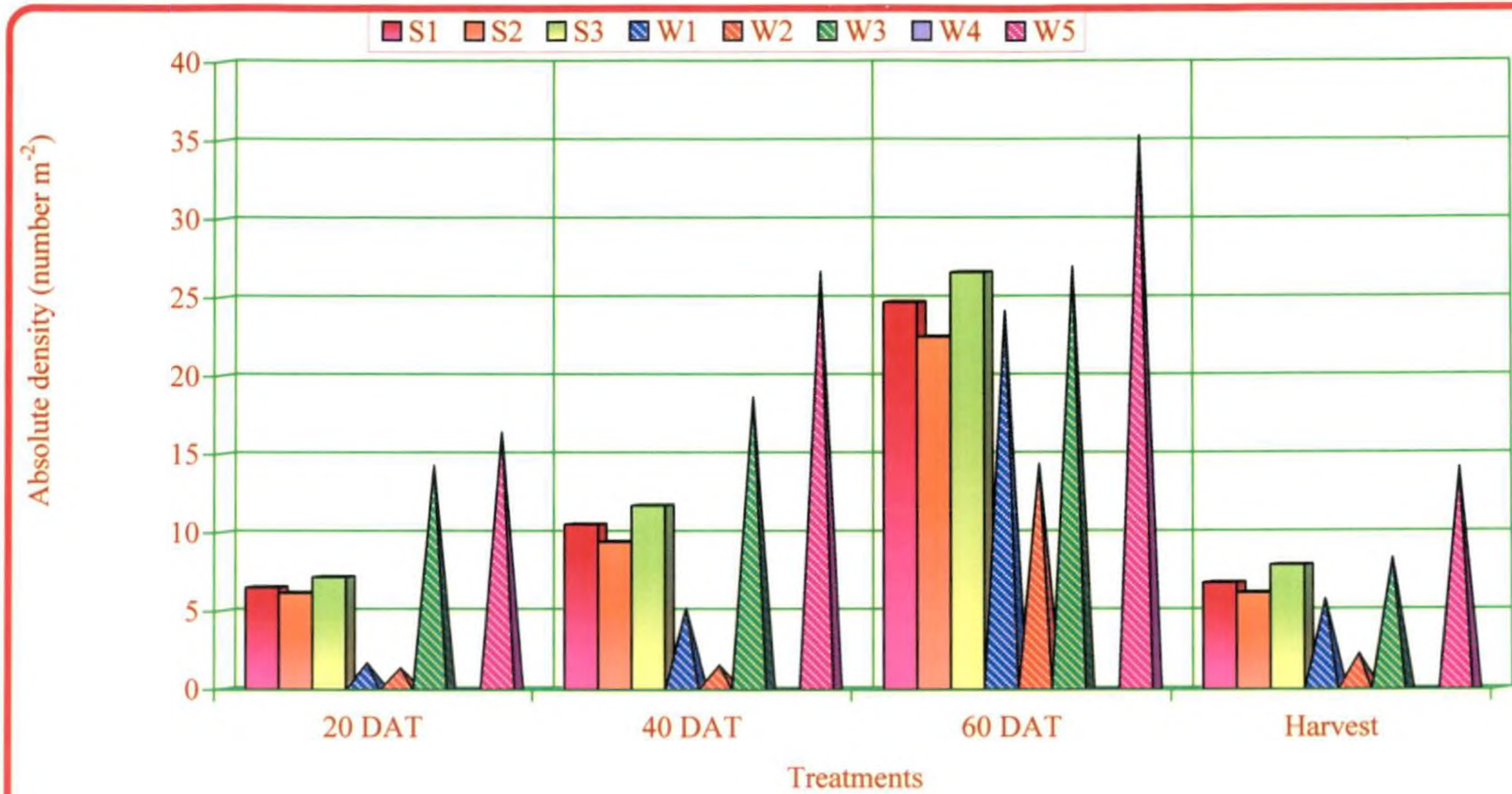


Fig. 3b. Main effect of spacing and weed management practices on absolute density of sedges

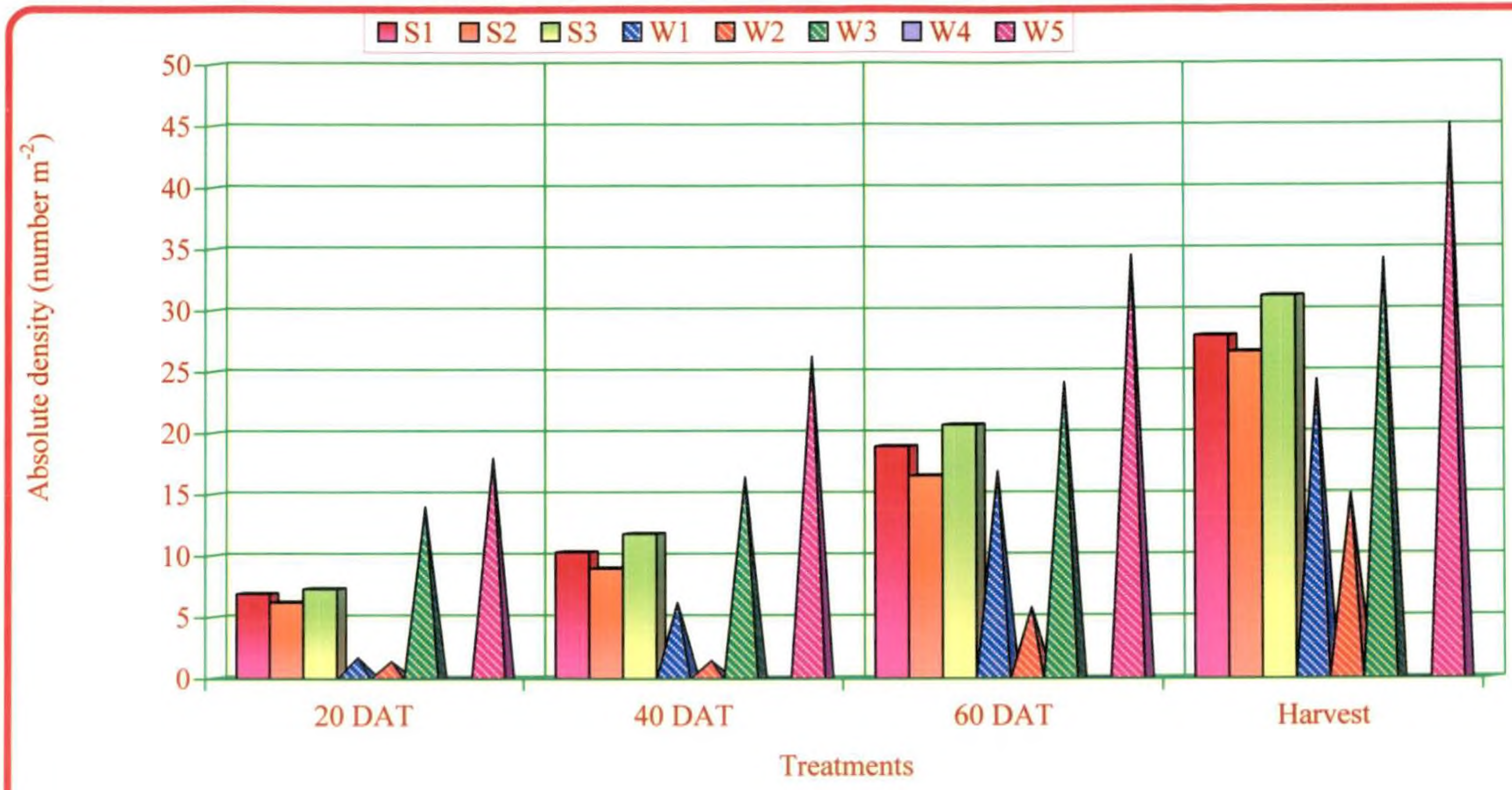


Fig. 3c. Main effect of spacing and weed management practices on absolute density of broad leaved weeds

thus causing reduced dry matter accumulation of weeds. Similar phenomena can be seen in the widest spacing (S_1) when compared to the medium spacing (S_2), where there is 12 per cent less crop plants. So those weed seedlings that were first to sprout utilized the available sunlight and other resources effectively to enhance their growth and dry weight and shaded those weed seedlings that sprouted late in the season leading to their poorer growth and establishment.

The weed management practices adopted influenced the growth of all type of weeds and also resulted in significant reduction in weed population. Apart from unweeded control (W_5) and weed free check (W_4) which recorded the highest and lowest absolute density and weed dry weight of all type of weeds respectively, it is found that W_2 (wherein pre-emergent anilofos + 2,4-D EE readymix application followed by post emergent 2,4-D sodium salt application) was significantly superior to W_1 (pre-emergent anilofos + 2,4-D EE readymix application followed by hand weeding) which in turn is significantly superior to W_3 (hand weeding twice). The dry weight accumulated by weeds had a significant bearing on weed control efficiency. This resulted in W_2 recording the highest weed control efficiency of all types of weeds compared to W_1 and W_3.

It has been proven beyond doubt by Biswas and Sattar (1993) that weed density significantly affected grain yield of rice when 40 or more weeds m^{-2} grew with rice. He also suggested that rice fields should be weeded in the wet season when a weed density of 17 to 42 plants m^{-2} and 14.1 to 22.3 g m^{-2} weed weight is recorded to prevent a reduction in rice grain yield beyond 10 per cent. In the present investigation, it was found that the absolute density of all types of weeds in unweeded control (W_5) was 147.09 and 224.01 at 40 and 60 DAT. Hand weeding twice (W_3) could reduce the weed density only to 77.95 and 84.05 at 40 and 60 DAT. The corresponding values for W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) are 23.53 and 66.15 at 40 and 60 DAT. It was also found that the weed dry weight of all types of weeds in unweeded control (W_5) was 111.55 g m^{-2} and 162.84 g m^{-2} at 40 and 60 DAT and hand weeding twice (W_3) could reduce the weed dry weight only to 47.11 g m^{-2} and 56.11 g m^{-2} at 40 and 60 DAT. The corresponding values for W_1 (anilofos + 2,4-

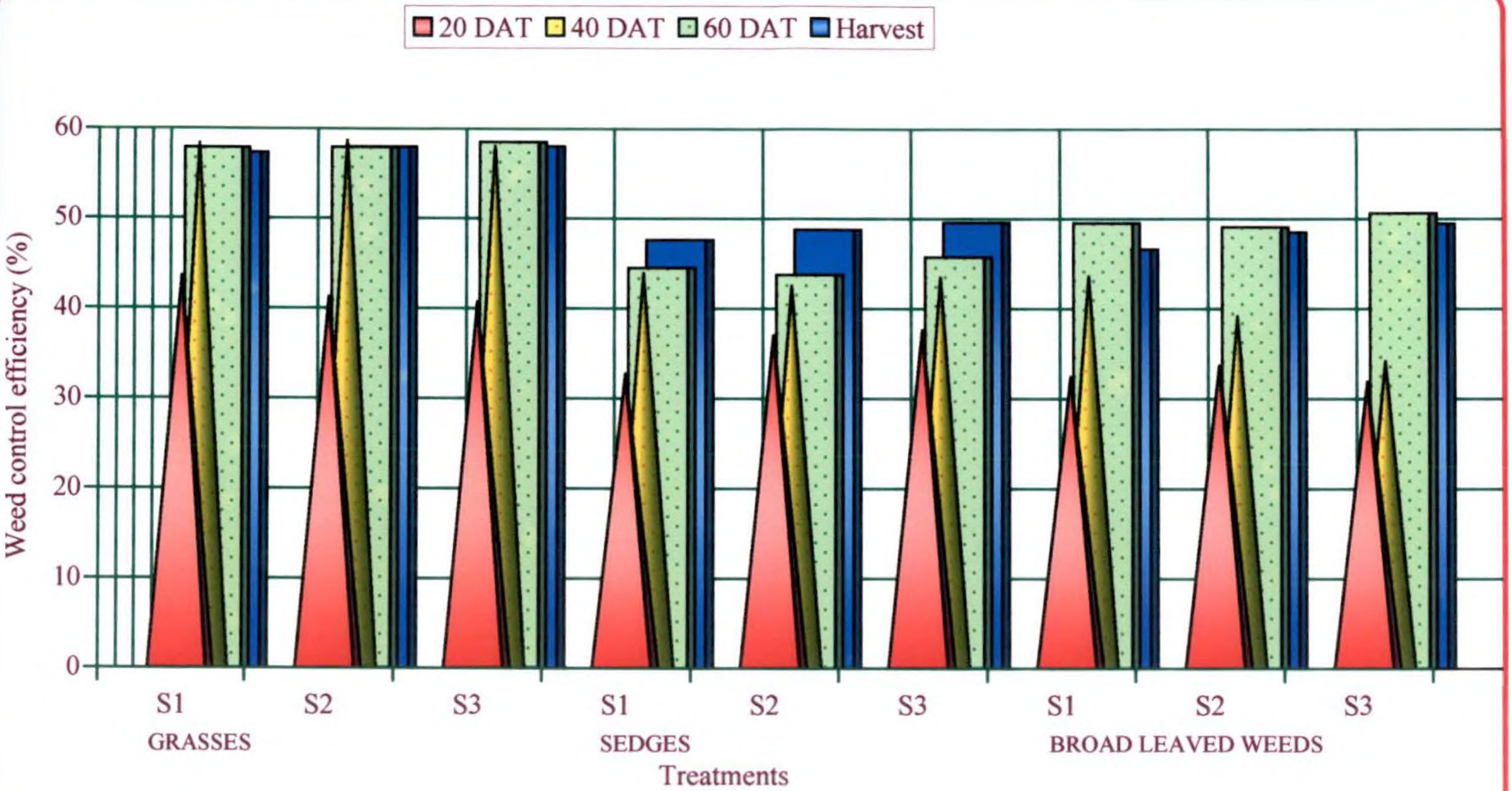


Fig. 4a. Main effect of spacing on weed control efficiency of grasses, sedges and broad leaved weeds

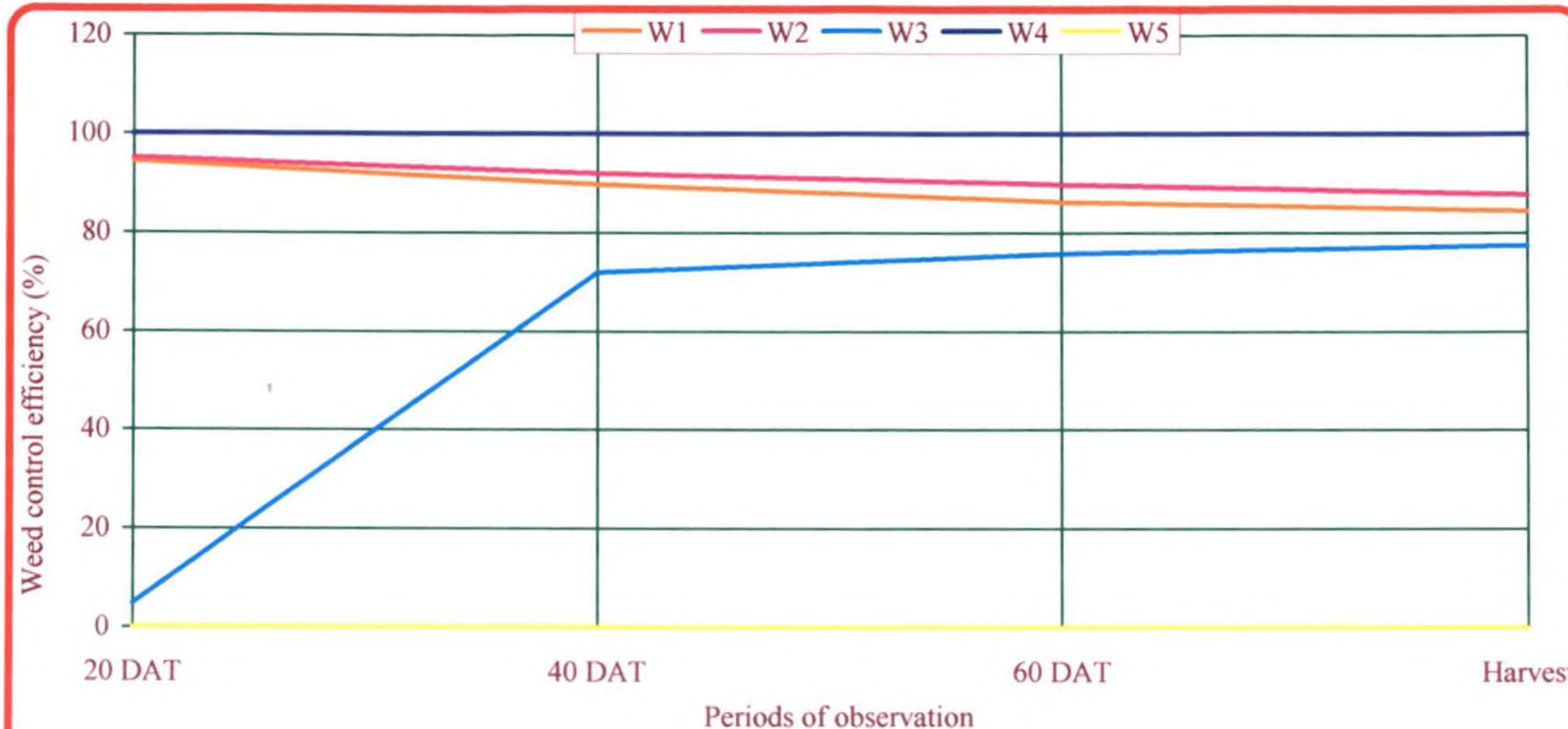


Fig. 4b. Main effect of weed management practices on weed control efficiency of grasses

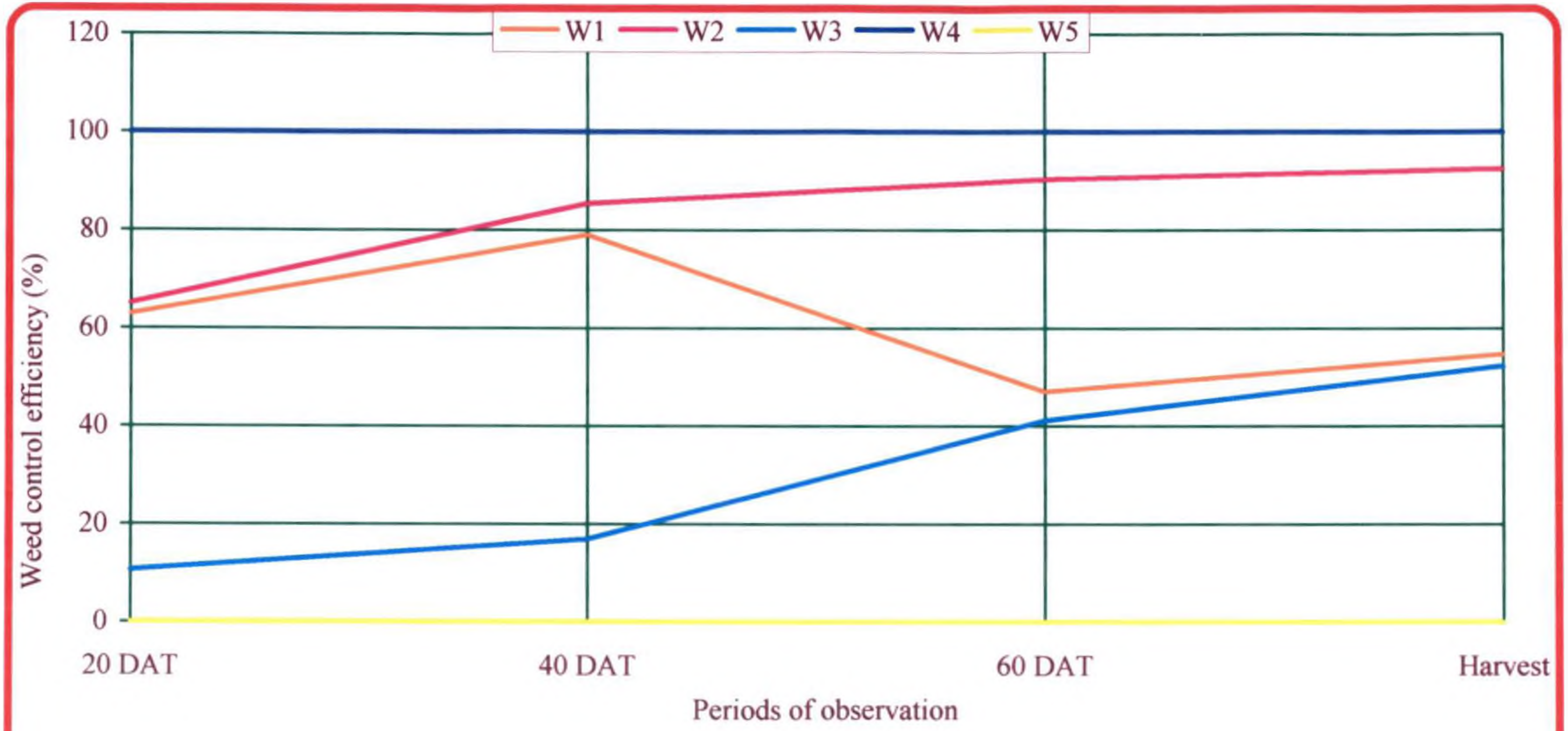


Fig. 4c. Main effect of weed management practices on weed control efficiency of sedges

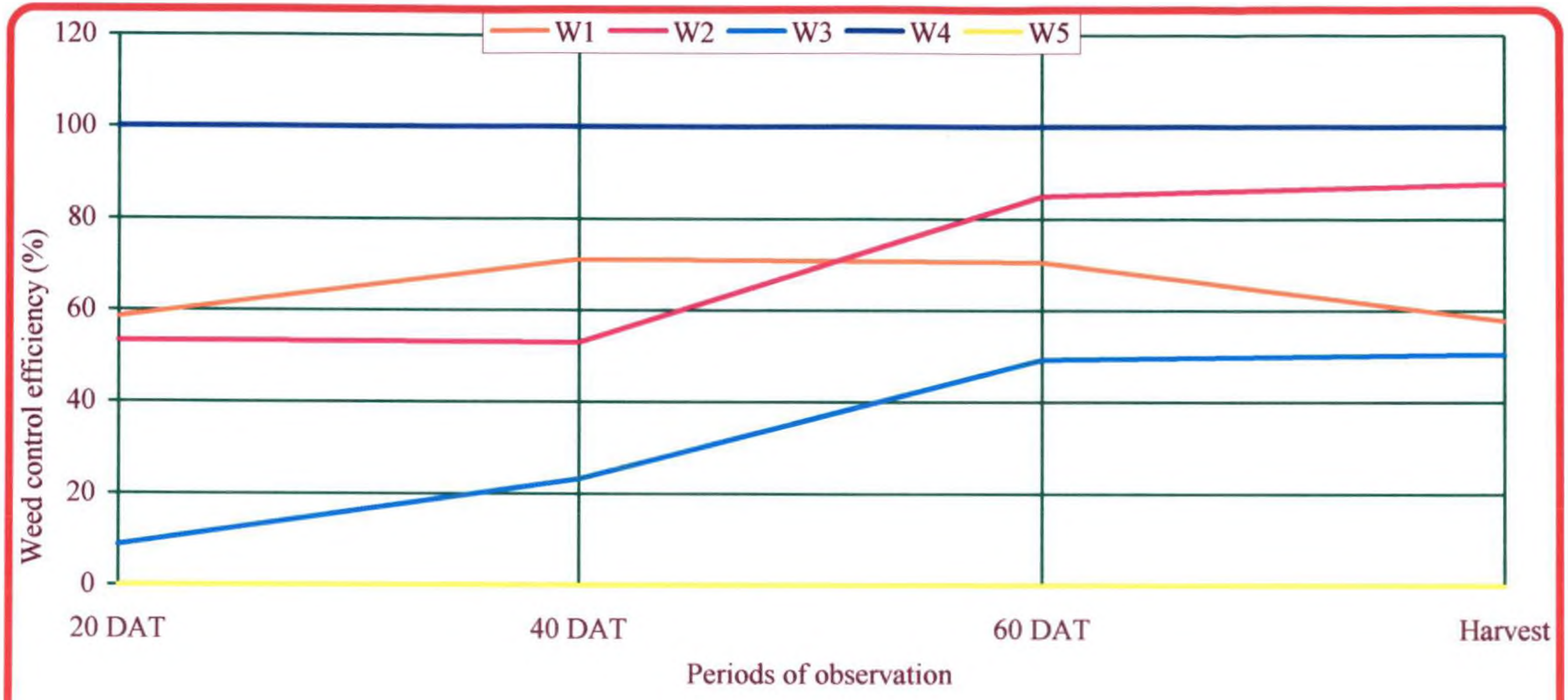


Fig. 4d. Main effect of weed management practices on weed control efficiency of broad leaved weeds

D EE at 6 DAT followed by one hand weeding at 20 DAT) were 14.97 g m^{-2} and 38.10 g m^{-2} at 40 and 60 DAT. For W_2, these values were 12.22 and 17.52 g m^{-2} respectively. This explains the superiority of W_2 in controlling weeds compared to W_1 and W_3. Biswas and Satter (1991) had earlier reported that rice uptake of nitrogen decreased as weed density increased and this was reflected in decreased yields (13 per cent reduction at 20 weeds m^{-2} and 17 per cent reduction at 40 weeds m^{-2}).

At 40 DAT, the absolute density of grasses in W_3, W_1 and W_2 were 42.85, 12.06 and 7.99; sedges 18.65, 5.17 and 1.56 and broad leaved weeds 16.39, 6.20 and 1.46 respectively and it resulted in grain yield reduction of 20.85, 14.58 and 7.96 per cent over the weed free check (W_4). Also it can be seen that grasses were the most dominant weed species and sedges and broad leaved weeds closely followed it.

5.3 NUTRIENT REMOVAL BY CROP AND WEEDS

The medium spacing (S_2) resulted in highest nutrient (N, P_2O_5 and K_2O) uptake by crop, which in turn was attributed to better crop growth and dry matter production at medium spacing. There was significant reduction in nutrient (N, P_2O_5 and K_2O) depletion by weeds at closer spacing compared to wider spacing. Corroboratory results were reported by Singh et al (1998). Maximum nutrient uptake was recorded by weed free treatment (W_4), while unweeded check (W_5) registered the minimum uptake values. The enhanced growth characters in weed free situation contributed to high dry matter production. The nutrient uptake being a product of dry matter production and nutrient content was also enhanced under such situations. It was evident that with minimum weeds to compete with and share resources, the uptake of nutrients by crop was facilitated, resulting in more vigorous crop growth and better yield.

Apart from failing to utilize the available nutrients, the weeds prevented crop plants from utilizing these nutrients as evidenced by the following illustration. N, P_2O_5 and K_2O uptake by weeds at harvest were 41.14, 10.95 and 24.78 kg ha^{-1} in unweeded check (W_5) while it was 94.86, 47.22 and 81.45 kg ha^{-}

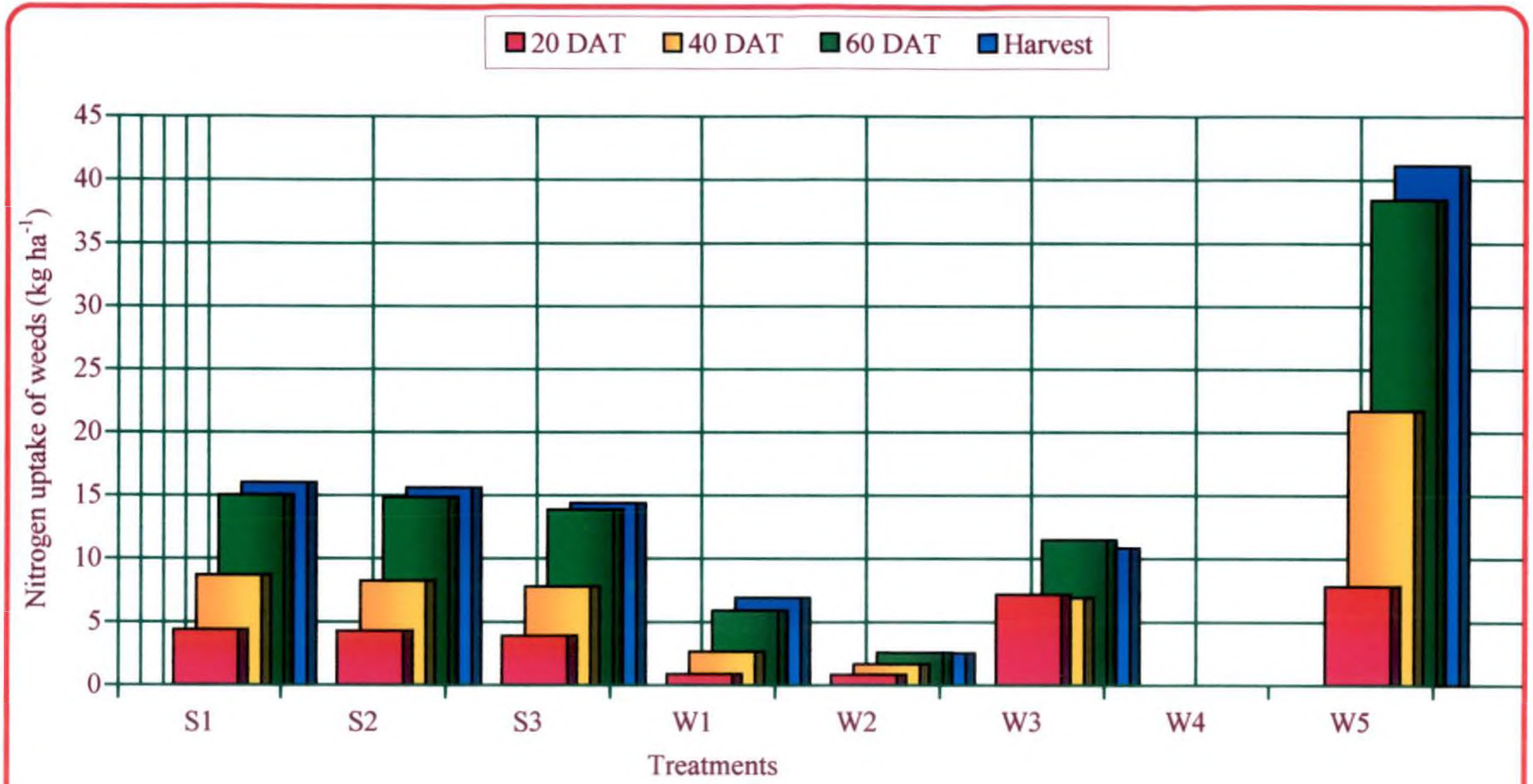


Fig. 5a. Main effect of spacing and weed management practices on nitrogen uptake of weeds

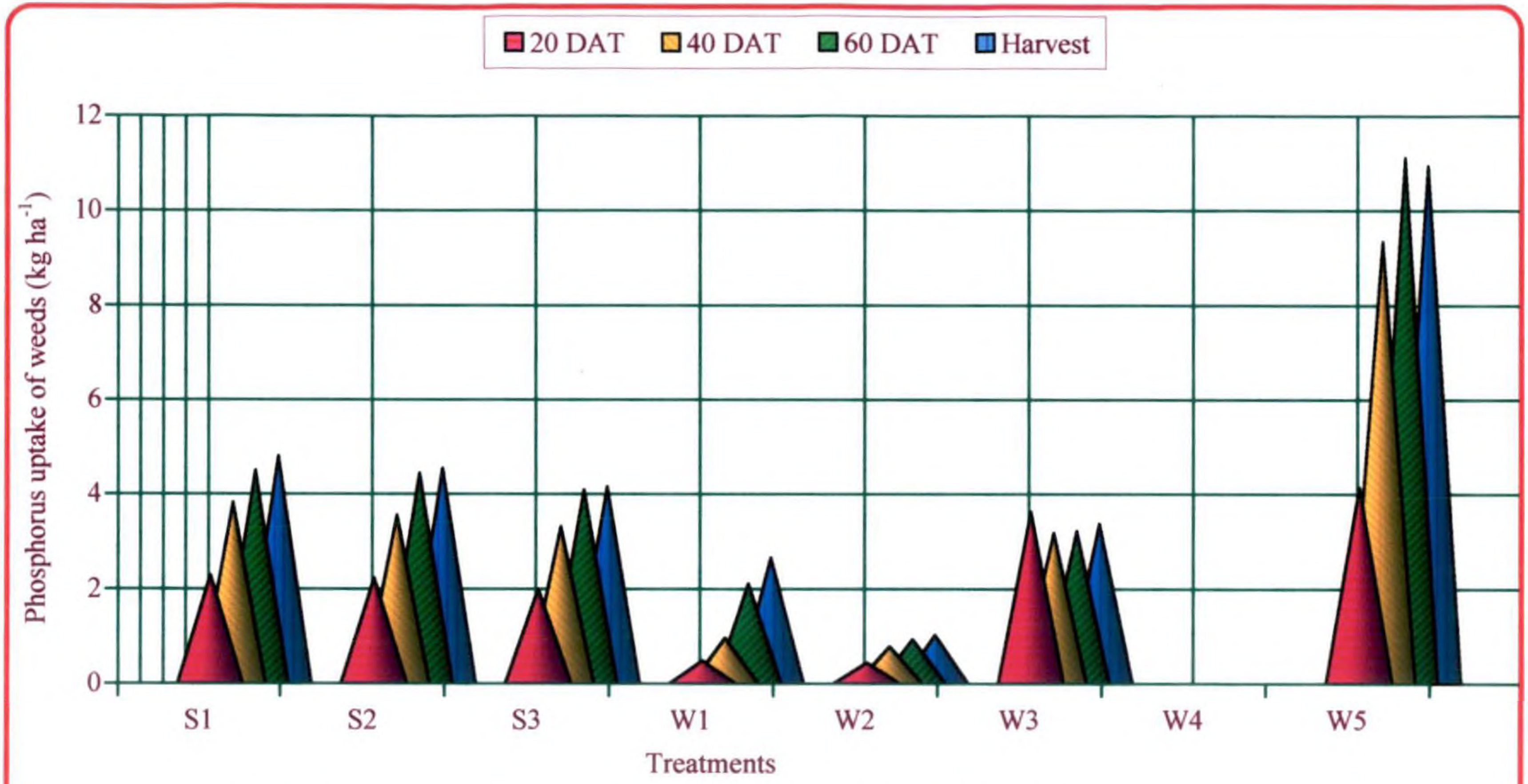


Fig. 5b. Main effect of spacing and weed management practices on phosphorus uptake of weeds

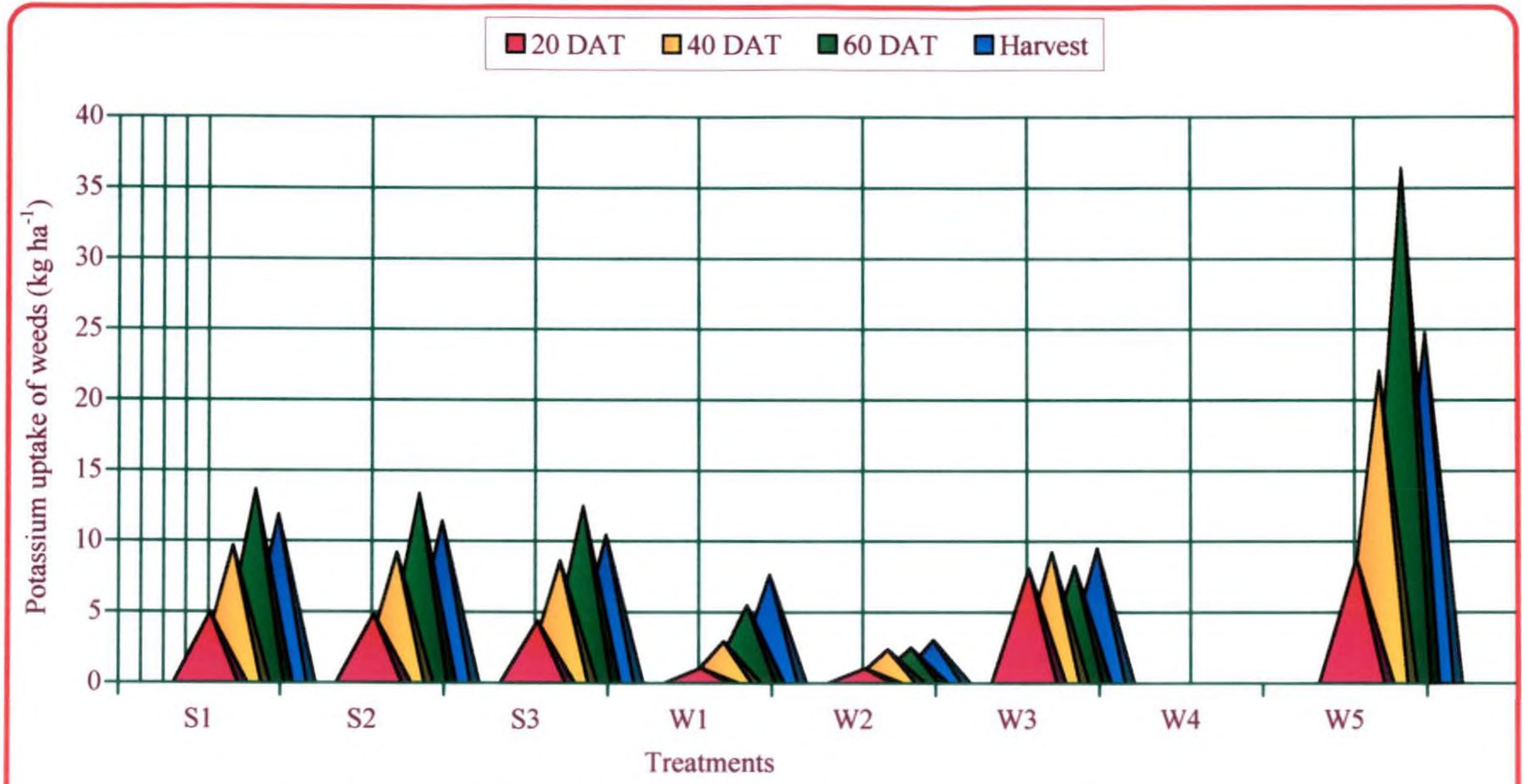


Fig. 5c. Main effect of spacing and weed management practices on potassium uptake of weeds

[1] by rice crop in the same field. Crop and weeds together could use only 136, 58.17 and 106.23 kg ha^{-1} N, P_2O_5 and K_2O clearly showing that some amount of nutrients remained unabsorbed in soil due to weed competition. However in weed free check, the total nutrient uptake by the crop at harvest were 174.2, 91.76 and 168.43 kg N, P_2O_5 and K_2O ha^{-1} respectively. Similar trend could be observed in works of Nanjappa and Krishnamurthy (1980) and Rajan (2000).

Throughout the crop period, the N and K_2O uptake by crop and weeds were higher than P_2O_5 uptake, as reported by Lakshmi (1983). Adoption of W_2 (anilophos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) resulted in a saving of 38.63, 9.92 and 21.74 kg ha^{-1} N, P_2O_5 and K_2O compared to unweeded control (W_5). The corresponding savings in terms of nutrients for W_1 (anilophos + 2,4-D EE at 6 DAT followed hand weeding at 20 DAT) and W_3 (hand weeding twice at 20 and 40 DAT) were 34.23, 8.29 and 17.13 kg ha^{-1} and 30.3, 7.57 and 15.26 kg ha^{-1} N, P_2O_5 and K_2O respectively. The nutrient uptake of crop and the nutrient uptake of weeds were inversely related through out the crop growth period. All treatments that recorded a higher nutrient (N, P_2O_5 and K_2O) uptake of crop registered a corresponding lower nutrient uptake of weeds.

The nutrient status of soil after experiment was influenced by both spacing and weed management practices. The nutrient content was highest in closest spacing (S_3) and lowest in medium spacing (S_2). This is because available soil nutrients were effectively utilised by crop in S_2 resulting in luxuriant crop growth and higher yield. Nutrient status was highest in weed free check, evidently because there was no nutrient removal by weeds. The fact that the unweeded control (W_5) recorded the lowest nutrient status strengthens this inference. The nutrient status of soil was found to be decreasing from W_2 to W_1 and W_3. This can be explained by analysing data on absolute density and dry weight of all types of weeds, which registered an increasing trend from W_2 to W_1 and W_3. So it can be inferred that the effective weed control by W_2 (anilophos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT) resulted in higher nutrient uptake by crop, lower nutrient uptake by weeds, lower soil nutrient status after experiment and helped to establish significant superiority over treatments W_1

(anilophos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) and W_3 (hand weeding twice at 20 and 40 DAT).

5.4 INCIDENCE OF SHEATH BLIGHT DISEASE

Sheath blight incidence was noticed at maturity phase of the crop. It was noticed that a 34 per cent increase in plant population (S_3) lead to 119.75 per cent increase in disease index while a 12 per cent lower plant population resulted in 64.81 per cent lesser disease index compared to the medium plant population (S_2), thus clearly showing that with decrease in plant population, there was lesser sheath blight incidence. Among weed management practices, the unweeded control (W_5) recorded the highest incidence and weed free check (W_4) recorded the lowest. This may be because the presence of weeds contributed to higher relative humidity of the microclimate leading to higher disease incidence.

5.5 ECONOMICS OF SPACING AND WEED MANAGEMENT

The results of present study speak clearly about the importance of spacing and weed management practices on crop yield. Compared to recommended spacing of 20 x 10 cm (S_2), adopting the widest spacing of 15 x 15 cm (S_1) resulted in 19.42 per cent and closest spacing of 15 x 10 cm (S_3) resulted in 41.51 per cent loss in net income. Any package of practices that can enhance yield need not always result in higher net returns and benefit-cost ratio as evidenced by weed free check (W_4). This treatment recorded superior yield compared to all other treatments but the expense incurred in keeping the field free of weeds is too high and unjustifiable. Apart from an experimental point of view, it has no relevance in farmer's field as evidenced by its lowest benefit-cost ratio. On the other hand, not undertaking any weed management practice (W_5) is also not a sound recommendation for the rice farmer as it recorded the lowest net income. The highest net income (Rs 58209 ha^{-1}) and benefit-cost ratio (2.07) were recorded by W_2. Apart from its favourable effect on crop growth characters and yield attributes, the economic advantage in adopting W_2 lies in its lower labour

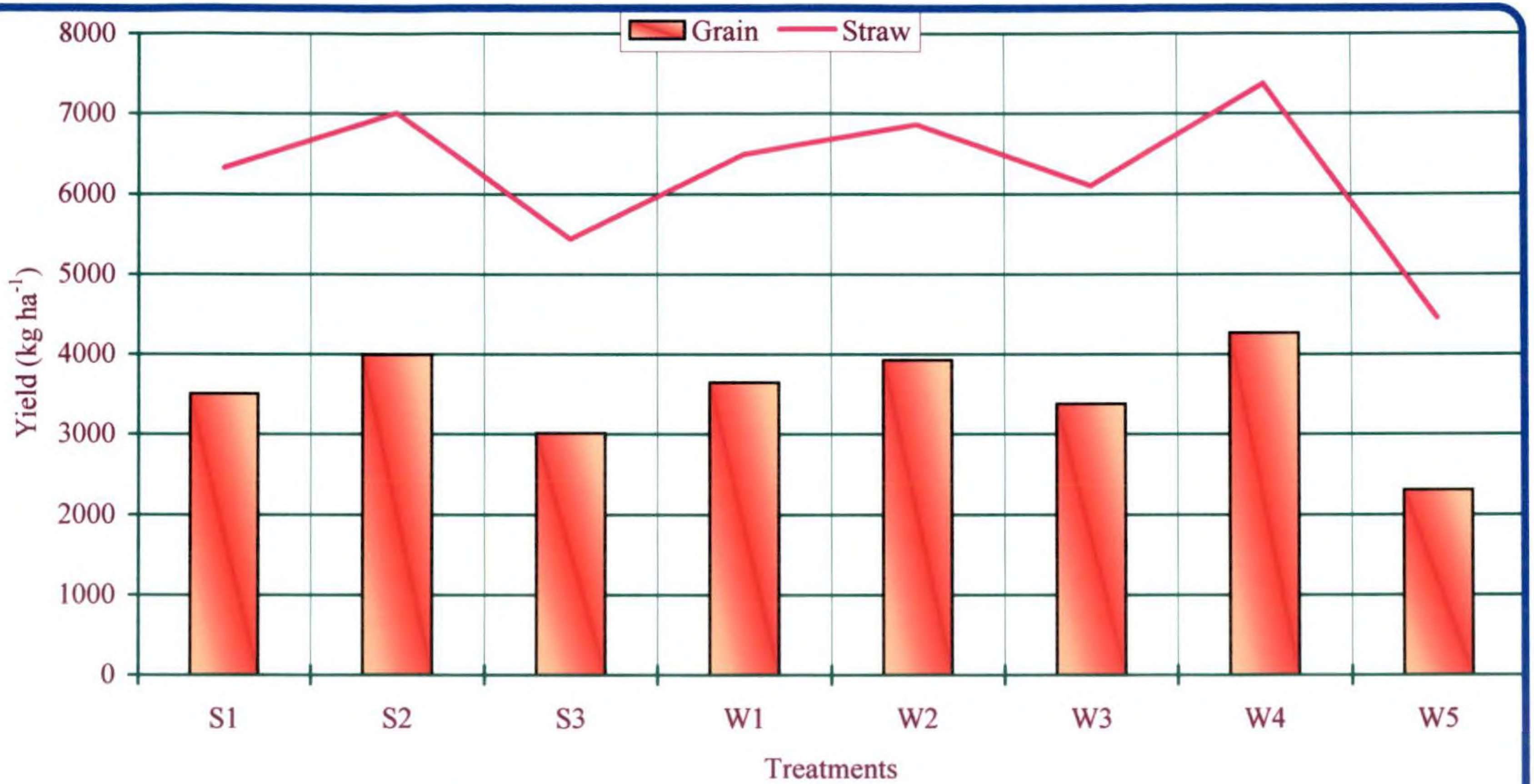


Fig. 6. Main effect of spacing and weed management practices on grain and straw yield

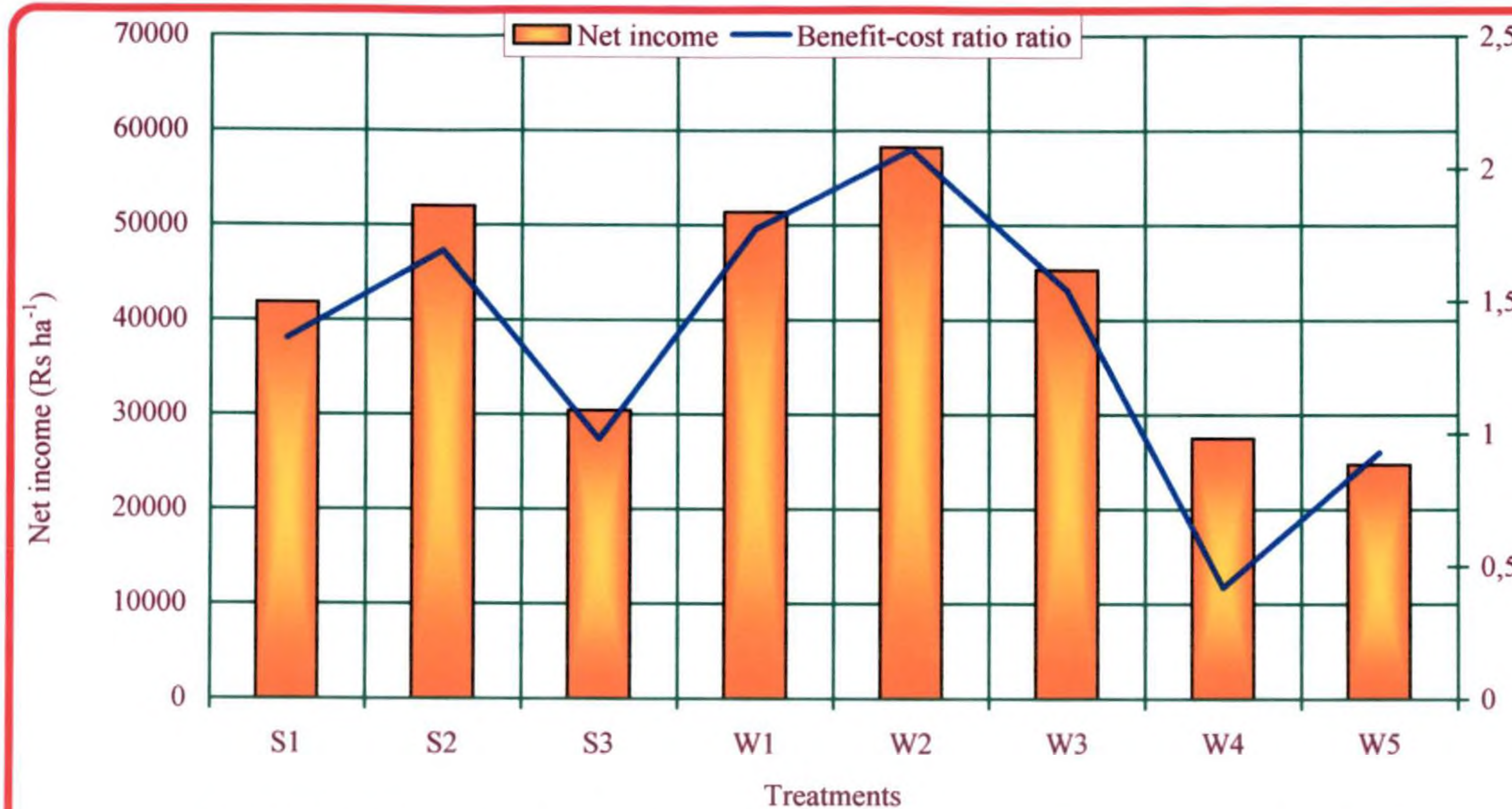


Fig. 7. Main effect of spacing and weed management practices on net income and benefit-cost ratio

requirement compared to W_1 and W_3. This is of immense importance for a state like Kerala where labour is scarce and costly.

Manual weeding is difficult, many a time due to continuous rains prevailing during rainy season and also due to scanty labour (Gogoi *et al.*, 2000). Ravindran (1976) reported that hand weeding on the 20th and 40th day after transplanting rice, although gave higher yields; the net profit was lower due to increased labour charges. Singh (1985) pointed out that hand weeding provided fairly good control of weeds because weeds from both inter and intra rows were removed, but it was laborious and expensive and also the cost-benefit ratio showed a negative value from hand weeding mainly due to very high labour cost. Singh *et al.*, (2000a) reported highest benefit-cost ratio of 2.50 by pre-emergent application of anilofos + 2,4-D EE followed by one hand weeding at 40 DAS. Prasad *et al.*, (1992) had opined that use of herbicides could save up to 75 per cent energy input than hand weeding. He also reported that energy use efficiency was higher with herbicides than with hand weeding. This explains the superiority and economic feasibility of pre-emergent anilofos + 2,4-D EE readymix application followed by post emergent 2,4-D sodium salt application. The S x W interaction influenced net income and benefit-cost ratio with s_2w_2 being superior to all other interactions and closely followed by s_2w_1 showing the superiority of medium spacing and herbicide treatments.

5.6 CORRELATION STUDIES

The results showed that grain yield of basmati rice was significantly and positively correlated with crop growth characters namely plant height, number of tillers per hill, dry matter production and leaf area index at panicle initiation stage. Among crop yield attributes, number of spikelets per panicle, number of filled grains per panicle, thousand grain weight, straw yield and harvest index were positively correlated with grain yield. A similar trend was noticed in rice cv. Jyothi under transplanted condition (Renjan, 1999).

Among weed parameters, weed dry weight, absolute density of weeds and nutrient uptake by weeds at all stages of crop growth recorded significant negative correlation with grain yield. It was evident that correlation coefficient varied with crop growth stages. Higher correlation between weed control efficiency and grain yield was recorded at 40 and 60 DAT which emphasises the beneficial effects of integrating pre-emergent herbicides like anilofos and 2,4-D EE with post emergent herbicides like 2,4-D sodium salt, to effectively control weeds during the critical period of crop-weed competition.

SUMMARY

6 SUMMARY

The present study entitled "Impact of plant population and weed management practices on performance of basmati rice" was undertaken at the Instructional Farm, College of Agriculture, Vellayani during the *mundakan* season (September 2001 to January 2002) of 2001-2002. The main objectives were to determine the effect of plant population on the growth and yield of basmati rice, to evolve a suitable and economic weed management strategy for basmati rice, to find out the effect of herbicide treatment on weed flora in rice and to study the nutrient depletion by crop and weeds.

The field experiment was laid out in Randomised Block Design with two factors, in fifteen treatment combinations and three replications. The factors included were spacings viz. 15 x 15 cm (S_1), 20 x 10 cm (S_2) and 15 x 10 cm (S_3) and weed management practices viz. anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT (W_1); anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT (W_2), hand weeding twice at 20 and 40 DAT (W_3), weed free check (W_4) and unweeded control (W_5).

The different spacings adopted influenced crop growth characters significantly. At 40 and 60 DAT and at harvest, the medium spacing of 20 x 10 cm (S_2) which is the recommended spacing for medium duration rice in the state, recorded the highest value in terms of plant height, number of tillers per hill and dry matter production, and were significantly superior to the other two spacings. Medium spacing of 20 x 10 cm (S_2) also resulted in highest leaf area index at panicle initiation stage.

The medium spacing (S_2) was significantly superior to all other spacings in increasing number of productive tillers per hill, number of spikelets per panicle, number of filled grains per panicle, thousand grain weight, grain yield, straw yield and harvest index. Yield loss due to weeds as indicated by weed index was highest (21.62) under closest spacing of 15x 10 cm (S_3) whereas it was only 13.82 in S_2. Regarding weight of panicle and chaff percentage, the medium spacing (S_2) was on par with widest spacing (S_1) and these two were significantly superior to the closest spacing (S_3).

The crop growth characters of basmati rice were significantly influenced by weed management practices. The plant height, number of tillers per hill, dry matter production of rice and leaf area index at panicle initiation stage were higher in plots treated with pre-emergent anilofos + 2,4-D EE readymix followed by post emergent 2,4-D sodium salt (W_2). W_1 (anilofos + 2,4-D EE readymix followed by hand weeding) was the next best treatment, while plots hand weeded twice (W_3) registered significantly lower values.

The yield attributing characters of basmati rice were significantly influenced by the weed management practices. Next to weed free check (W_4), anilofos + 2,4-D EE readymix followed by 2,4-D sodium salt (W_2) recorded the maximum number of productive tillers per hill, panicle weight, number of spikelets per panicle, number of filled grains per panicle, thousand grain weight, grain yield, straw yield and harvest index. Anilofos + 2,4-D EE readymix followed by hand weeding (W_1) was the next best treatment. Except harvest index, for all other yield attributes, the two herbicide treatments (W_2 and W_1) were significantly superior to hand weeding twice (W_3). However, W_1 and W_3 were on par with respect to harvest index. The chaff percentage and yield loss due to weeds as indicated by weed indices were maximum under unweeded control (W_5).

As far as treatment combinations were concerned, at 60 DAT, plant height, number of tillers per hill and dry matter production of s_2w_2 was comparable with s_2w_4. Crop dry matter production of s_2w_2 was comparable with s_2w_1 at 40 DAT and at harvest. Both were significantly inferior to s_2w_4 during the same period of observations. Leaf area index at panicle initiation stage in s_2w_2 was on par with s_2w_1 and next only to s_2w_4 and s_1w_4. Grain yield and straw yield of s_2w_2 was comparable with s_1w_4 but significantly inferior to s_2w_4. Weed index of s_2w_2 was superior to all other interactions except s_1w_4, s_2w_4 and s_3w_4 i.e, interactions involving weed free check (W_4).

Echinochloa colona (L.) Link, *Echinochloa crus-galli* (L.) Beauv. and *Leersia hexandra* S. W. were the most important grassy weeds present in the experimental field. Among sedges, *Cyperus iria* L., *Cyperus difformis* L. and *Fimbristylis miliaceae* (L.) Vahl. were the predominant ones. *Ludwigia parviflora* Roxb. and *Monochoria vaginalis* (Burm. F.) Kunth. were the most problematic broad leaved weeds observed.

With respect to absolute density of all types of weeds, in general, at all stages of observations, the medium spacing of 20 x 10 cm (S_2) registered the lowest values and it was significantly superior to S_1 and S_3. However, at harvest, absolute density of sedges in S_2 was comparable with that in S_1 (15 x 15 cm), which was on par with S_3 (the closest spacing of 15 x 10 cm). Also at harvest, the absolute density of broad leaved weeds in S_2 was on par with S_1. With respect to weed control efficiency of sedges, at 20 DAT, the closest spacing (S_3) recorded the highest value, which was on par with S_2. With regard to weed control efficiency of broad leaved weeds, at harvest, S_2 was the best spacing tried and it was on par with S_3 and superior to S_1.

Unweeded control registered the maximum weed growth through out the growth period of rice. Grasses constituted the major portion of the weed population through out the rice growing period. The use of herbicides (W_1 and W_2) was effective than hand weeding twice (W_3) in controlling weeds. Anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT (W_2) controlled grassy weeds better than other treatments. It was closely followed by anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT (W_1) which was better than hand weeding twice. Use of herbicides (W_1 and W_2) for controlling sedges and broad leaved weeds was found to be more effective than hand weeding twice (W_3). Pre-emergence application of anilofos + 2,4-D EE at 6 DAT followed by post emergence application of 2,4-D sodium salt at 20 DAT (W_2) suppressed sedges and broad leaved weed population during the crop growing season and it was better than anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT (W_1).

The absolute density and dry weight of grasses, sedges and broad leaved weeds was suppressed by pre-emergence application of anilofos + 2,4-D EE readymix followed by post emergence 2,4-D sodium salt (W_2) through out the crop season (W_2). This treatment was better than pre-emergence application of anilofos + 2,4-D EE followed by one hand weeding at 20 DAT (W_1). Hand weeding twice at 20 and 40 DAT (W_3) was found to be significantly inferior to both these treatments.

Pre-emergence anilofos + 2,4-D EE readymix followed by post emergence 2,4-D sodium salt (W_2) had higher weed control efficiency of grasses, sedges and broad leaved weeds. The second best treatment with respect to weed control efficiency was W_1, which was superior to hand weeding twice (W_3).

At 40 DAT, absolute density of grasses and sedges in s_2w_2 was comparable with s_1w_2 and s_2w_2 and significantly superior to all other interactions except s_1w_4, s_2w_4 and s_3w_4 i.e., interactions involving weed free check (W_4). At 60 DAT absolute density of grasses in s_2w_2 was on par with s_1w_2 and was inferior to s_1w_4, s_2w_4 and s_3w_4. At harvest, s_2w_2 was comparable with s_1w_2 in reducing the dry weight of broad leaved weeds. At 20 and 40 DAT, s_2w_2 was found to be on par with s_1w_2 and s_3w_3 in controlling sedges. At harvest s_2w_2 was found to be on par with s_1w_2 and s_3w_3 in controlling broad leaved weeds.

Highest uptake of nutrients (nitrogen, phosphorus and potassium) by crop was recorded by weed free check (W_4) while unweeded control (W_5) had the lowest uptake during the entire crop season. Unchecked weed growth exploited available nutrients, water and sunlight resulting in better weed growth and better dry matter production of weeds through out the crop period. Application of pre-emergent anilofos + 2,4-D EE readymix followed by post emergent 2,4-D sodium salt (W_2) significantly reduced the nutrient uptake by weeds and thus indirectly increased the nutrient uptake of crop.

The closest spacing of 15 x 10 cm (S_3) and unweeded control (W_5) recorded higher sheath blight disease indices, and were significantly inferior to all other treatments. The medium spacing of 20 x 10 cm (S_2) was superior to all other spacings in increasing the net income and benefit-cost ratio. The results revealed higher benefit-cost ratio and net income for W_2 (anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT). This was closely followed by W_1 (anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT) which was found to be superior to hand weeding twice at 20 and 40 DAT (W_3) in enhancing benefit-cost ratio and net income. Among the interactions, s_2w_2 was found to be superior to all other interactions in increasing the net income and benefit-cost ratio.

The present investigation revealed the superiority of adopting 20 x 10 cm spacing and applying pre-emergent herbicide mixture anilofos + 2,4-D EE @ 0.4 + 0.53 kg ai ha^{-1} at 6 DAT followed by 2,4-D sodium salt @ 1 kg ai ha^{-1} at 20 DAT on weed control, yield and economics of basmati rice.

FUTURE LINE OF WORK

The study was carried out only during the *mundakan* season, at a single location. The effect of different treatments on weed control efficiency in virippu and punja seasons must be investigated. Also the present results need multi-location trials to verify the results over the major rice growing tracts of Kerala. The changes in weed flora over a period of time and in subsequent crops need detailed investigation. A weed management strategy involving pre-emergent herbicide mixtures in conjunction with post-emergent herbicides or hand weeding for rice based cropping system must be worked out to explore the possibility of reducing herbicide use in subsequent crops in the system with out compromising yield.

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IMPACT OF PLANT POPULATION AND WEED MANAGEMENT PRACTICES ON THE PERFORMANCE OF BASMATI RICE

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8 ABSTRACT

A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani during the *mundakan* season of 2001-2002 in order to determine the effect of spacing and weed management practices on the yield of scented basmati rice cv. Pusa Basmati-1.

The field experiment was laid out in Randomised Block Design with two factors, in fifteen treatment combinations and three replications. The factors included were spacings viz. 15 x 15 cm (S_1), 20 x 10 cm (S_2) and 15 x 10 cm (S_3) and weed management practices viz. anilofos + 2,4-D EE at 6 DAT followed by hand weeding at 20 DAT (W_1), anilofos + 2,4-D EE at 6 DAT followed by 2,4-D sodium salt at 20 DAT (W_2), hand weeding twice at 20 and 40 DAT (W_3), weed free check (W_4) and unweeded control (W_5).

Transplanting basmati rice at 20 x 10 cm, which is the recommended spacing for medium duration rice in Kerala, enhanced the growth characters of rice such as plant height, tiller count and leaf area index. Dry matter production and nutrient uptake of rice were also enhanced by this spacing. The count of grasses, sedges and broad leaved weeds and the total weed population was reduced by this practice resulting in higher net income and benefit-cost ratio. The dry matter production of weeds and nutrient uptake by weeds were also significantly lower at this spacing compared to the other two spacings.

Adoption of pre-emergence application of anilofos + 2,4-D EE @ 0.4 + 0.53 kg ai ha^{-1} at 6 DAT followed by 2,4-D sodium salt @ 1 kg ai ha^{-1} at 20 DAT resulted in enhanced plant height, tiller count, leaf area index, dry matter production and nutrient uptake of rice. The yield attributes and grain yield were significantly increased by this practice and the weed index was significantly reduced. The total weed population, weed dry matter production and nutrient uptake were also reduced and weed control efficiency was increased by this treatment.

The treatment combination involving recommended spacing of 20 x 10 cm and pre-emergence application of anilofos + 2,4-D EE @ 0.4 + 0.53 kg ai ha^{-1} at

6 DAT followed by 2,4-D sodium salt @ 1 kg ai ha^{-1} at 20 DAT, recorded higher dry matter production and nutrient uptake of rice. This resulted in higher grain yield and lower weed index than other interactions. The lowest total weed count, weed frequency and weed density at all stages of observation were registered for this interaction. Moreover it helped to reduce the weed dry matter production and nutrient uptake.

Compared to the existing practice of hand weeding twice at 20 and 40 DAT, all weed management practices except unweeded control, showed their superiority in augmenting the grain yield and thus increased the net income and benefit cost ratio.