

DIRECT AND RESIDUAL EFFECT OF HERBICIDES IN A RICE-WHEAT CROPPING SYSTEM

GOPINATH, K.A.



DIVISION OF AGRONOMY
INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI-110012

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DIRECT AND RESIDUAL EFFECT OF HERBICIDES IN A RICE-WHEAT CROPPING SYSTEM

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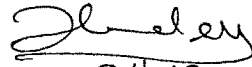
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in partial fulfilment of the requirements
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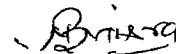
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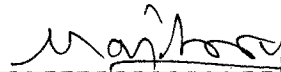
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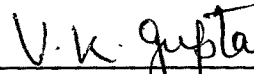
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(Dr. V.K. Gupta)

Dr. Jitendra Pandey
Principal Scientist

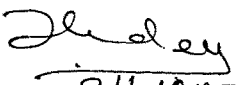
Division of Agronomy
Indian Agricultural Research Institute
New Delhi-110 012

CERTIFICATE

This is to certify that the thesis entitled "**Direct and residual effect of herbicides in a rice-wheat cropping system**" submitted to the Faculty of Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy in Agronomy**, embodies the results of *bona fide* research work carried out by **Mr. Gopinath, K.A.**, under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

All the assistance and help received during the course of the investigation have been duly acknowledged by him.

New Delhi
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9/4/2003
(Jitendra Pandey)
Chairman
Advisory Committee

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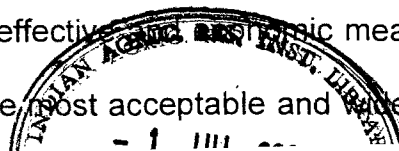
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INTRODUCTION

Rice-wheat system is a predominant cropping system in India. It is estimated to be followed in 10.5 million hectares, which is mostly concentrated in the irrigated tract of five Indo-gangetic states Uttar Pradesh, Punjab, Haryana, Bihar and West Bengal. This system contributes more than one-fourth to total foodgrain production and is backbone of food security in India. Hence, rice-wheat cropping system will remain as pivot in future planning for food self-sufficiency at national level on sustainable basis. In recent years, however, this cropping system is showing signs of "fatigue" due to various reasons. One of the puissant factors that markedly brings down the productivity of the system is severe weed infestation. Continuous cropping of morphologically changed varieties of these two crops and shifting paradigm of sowing have led to manifold increase in the incidence of weeds in rice-wheat zones causing heavy yield losses (Pandey and Singh, 1997). Crop yield losses due to weeds have been estimated to range from 15 to 45 per cent in transplanted rice (Mukhopadhyay *et al.*, 1985; Raju and Reddy, 1995; Nandal *et al.*, 1999b) and 10 to 57 per cent in wheat (Pandey and Singh, 1997; Chopra *et al.*, 1999; Pandey, 2002a). Thus, timely and effective control of weeds is pivotal to augment the productivity of rice and wheat.

The progressive modernization of Indian agriculture involving intensive use of herbicides is gaining popularity in recent years. In many instances, herbicides offer the most practical, effective and economic means for controlling weeds. Chemical weed control is the most acceptable and widely used measure



in many rice-wheat zones of Indo-gangetic plains. Herbicides are used in about 80 per cent of rice and 50 per cent of wheat area in Punjab and Haryana.

Anilofos and pretilachlor have been reported to be effective against most of the weeds in rice. Lately, flufenacet (Foe 5043) is reported to be effective at very low doses particularly against grassy weeds in rice (Deege *et al.*, 1995). Isoproturon is a major input in wheat production since 1978 (Gill *et al.*, 1978) and has stabilized its production by shielding at least a quarter of loss in the potential yield of wheat (Malik and Singh, 1993). But the most rampant weed *Phalaris minor* has already developed resistance against it thereby compounding the problem of its control. Hence, alternate herbicides with different mode of actions are the need of the day. The performance of new herbicide sulfosulfuron and uncommon metribuzin has been found promising against grassy and broadleaved weeds in wheat (Pandey, 1999; Chhokar *et al.*, 2001; Das and Yaduraju, 2002; Pandey *et al.*, 2002a).

Agriculture has always had and always will have environmental as well as other concerns. The benefits of herbicide use must always be weighed against their risks. Widespread and increasing use of herbicides are causing concern about their potential ecological effects. Earlier studies (Nandal and Singh, 1994a; Radhamani *et al.*, 1997; Dubey *et al.*, 1998; Balasubramanian *et al.*, 1999) showed that anilofos, pretilachlor and metribuzin persist in soil for varying length of time depending upon dose, soil and agroclimatic conditions. However, information available on the environmental fate of new herbicides flufenacet and sulfosulfuron is scanty in literature. Hence, information on direct and residual

effects of herbicides is important to use them safely and effectively in a rice-wheat cropping system.

In view of above, an experiment entitled "**Direct and residual effect of herbicides in a rice-wheat cropping system**" was conducted at the Indian Agricultural Research Institute, New Delhi with the following objectives:

1. To study the direct and residual effects of herbicides on crops and weeds.
2. To study the persistence of herbicides in soil and crop.
3. To suggest economically viable weed control measures for rice-wheat cropping system.

REVIEW OF LITERATURE

An attempt has been made in this chapter to review the available information relating to weed management in transplanted rice and wheat separately and in sequence as well as their residual effect on succeeding crops. However, information on residual effect of herbicides in rice-wheat cropping system is scarce in literature.

Major emphasis is laid on the work done on effect of herbicides on weed flora, crop-weed competition, besides information on residual effect and persistence of herbicides.

2.1 Weed flora

2.1.1 Weed species in rice

In Punjab, Chela and Gill (1980) observed preponderance of *Ischaemum rugosum* and *Caesulia axillaris* in rice. In West Bengal, *Echinochloa colona*, *Paspalum scrobiculatum*, *Cyperus difformis*, *Cyperus iria*, *Fimbristylis littoralis*, *Ludwigia parviflora*, *Oldenlandia dichotoma*, *Sphenoclea zeylanica* and *Monochoria vaginalis* were the predominant weed species in rice (De and Mukhopadhyay, 1983; Bhowmick *et al.*, 2000). In Himachal Pradesh, *Echinochloa crusgalli*, *Echinochloa colona*, *Ammania baccifera*, *Cyperia iria*, *Cyperus esculentus*, *Cyperus difformis*, *Panicum sp.*, *Aeschynomene indica*, *Monochoria vaginalis*, *Setaria glauca* and *Commelina forskalli* were the dominant weed species in the rice field (Singh and Kharawara, 1984; Angiras and Rana, 1998). At Samastipur, the important weed species observed in rice field were

Physalis minima (5%), *Rungia repense* (3%), *Dactyloctenium aegyptium* (2.5%) and *Digitaria adscedens* (Pandey and Thakur, 1988). In Gujarat, Patel *et al.* (1988) observed preponderance of *Panicum colona*, *Sporobolus indicus*, *Caesulia axillaris*, *Cynotis* sp., *Ammania baccifera* and *Ludwigia octovalvis* in rice field. In Madhya Pradesh, *Cynodon dactylon*, *Eleusine indica*, *Paspalum distichum*, *Cyperus* sp., *Commelina benghalensis*, *Ammania baccifera*, *Caesulia axillaris*, *Cynotis axillaris* and *Euphorbia* sp. were the dominant weed species in rice (Kulmi, 1991). In Karnataka, Reddy *et al.* (1995) observed dominance of *Panicum repens*, *Cyperus difformis* and *Lidernia parviflora* in rice.

At Karnal, *Echinochloa colona*, *Echinochloa crusgalli*, *Echinochloa glabrescens*, *Cyperus iria*, *Paspalum paspalodes* and *Eclipta alba* were rampant in rice (Singh *et al.*, 1997). At Kaul (Haryana), *Echinochloa crusgalli* (61%) and *Cyperus iria* (28%) were the predominant weed species while, *Ischaemum rugosum*, *Paspalum distichum* and *Ammania* spp. were sparsely present (Dhiman *et al.*, 1998; Nandal *et al.*, 1999a). In Pondicherry, the most common weed species that infested rice field were *Echinochloa colona*, *Cyperus rotundus*, *Cyperus iria*, *Cyperus difformis* and *Ludwigia parviflora* (Rammohan *et al.*, 1999). At Ghaghraghat (UP), Singh *et al.* (1999b) observed the preponderance of *Cynodon dactylon*, *Leptochloa chinensis*, *Echinochloa crusgalli* and *Echinochloa colona* among grasses, *Cyperus rotundus*, *Fimbristylis miliacea*, *Cyperus iria* and *Cyperus difformis* among sedges and *Caesulia axillaris*, *Commelina benghalensis* and *Cynotis axillaris* among broadleaved weeds in rice. At Jorhat, the major weeds observed in the rice field were *Echinochloa crusgalli*, *Sagittaria guacyansis*, *Scirpus juncooides*, *Monochoria vaginalis*, *Fissendocarpa linifolia*, *Hyderolea zeylanica* and *Paspalum conjugatum*. The composition of grasses,

sedges and broadleaved weeds was 31.4, 36.3 and 32.3%, respectively (Gogoi *et al.*, 2000; Rajkhowa *et al.*, 2001).

At Hyderabad, Reddy *et al.* (2000) noted preponderance of *Echinochloa colona*, *Paspalum distichum*, *Cyperus iria*, *Cyperus difformis*, *Scirpus supinus*, *Ammania baccifera*, *Marsilea quadrifoliata*, *Caesulia axillaris* and *Ottelia alismoidis* in rice. At New Delhi, the predominant weed species found in rice field were *Echinochloa colona*, *Echinochloa crusgalli*, *Leptochloa chinensis*, *Eclipta alba* and *Commelina benghalensis* (Chander and Pandey, 2001). At Coimbatore, *Echinochloa colona* and *Leptochloa chinensis* among grasses, *Cyperus iria* and *Cyperus difformis* among sedges and *Eclipta alba* among broadleaved were most common weeds in rice (Jayakumar and Anandakrishnan, 2001).

2.1.2 Weed flora in wheat

At Bhubaneswar, grasses were predominant (58.56%) followed by non-grasses (34.24%) and sedges (7.01%). Among the grasses, *Leptochloa chinensis* (21%), *Echinochloa colona* (11%), *Cynodon dactylon* (11%) and *Digitaria sanguinalis* (7%) and among the broadleaved weeds, *Chenopodium album* (7%), *Eclipta alba* (3.5%), *Amaranthus viridis* (3%) and *Blumea lacera* (10%) were the most common. At Hisar, *Phalaris minor*, *Avena ludoviciana*, *Chenopodium album*, *Rumex retroflex*, *Lathyrus aphaca*, *Vicia sativa*, *Anagallis arvensis* and *Melilotus indica* were predominant weed species in wheat (Balyan, 1999; Balyan, 2001). At Pantnagar, Singh *et al.* (1999d) observed preponderance of *Chenopodium album*, *Melilotus alba*, *Melilotus indica*, *Fumaria parviflora*, *Anagallis arvensis*, *Coronopus didymus*, *Vicia sativa* and *Medicago denticulata*.

At Karnal, *Phalaris minor* was rampant. The other notable weeds were *Medicago denticulata*, *Melilotus alba* and *Cyperus rotundus* (Chhokar et al., 2001b). In Himachal Pradesh, Saini and Singh (2001) found prevalence of *Phalaris minor* (42%) and *Avena fatua* (40%). Other weed species that occurred in wheat field were *Lolium temulentum*, *Alopecurus myosuroides*, *Vicia sativa* and *Anagallis arvensis*. At Gurdaspur, Sardana (2001a) observed preponderance of *Anagallis arvensis* (57.6%), *Lepidium sativum* (24.8%), *Vicia sativa* (9.3%), *Medicago denticulata* (6.2%) and *Lathyrus aphaca* (2.1%) among the broadleaved weeds and *Avena ludoviciana* among grasses but the population of latter was small compared to broadleaved weeds, in wheat.

At Jabalpur, the important weed species found in wheat field were *Phalaris minor*, *Medicago hispida*, *Chenopodium album*, *Rumex dentata*, *Lathyrus aphaca* and *Vicia sativa* (Singh et al., 2001b). At Ranchi, Singh and Saha (2001) found *Cynodon dactylon*, *Brachiaria mutica* and *Echinochloa crusgalli* and *Phalaris minor* most common among grasses, *Chenopodium album* among non-grasses and *Cyperus rotundus* among sedges in wheat. At Delhi, *Phalaris minor* (184 plants/m²), *Avena ludoviciana* (15/m²) and *Melilotus indica* (30/m²) were the dominant weed species in wheat. Besides, *Chenopodium album*, *C. murale*, *Anagallis arvensis*, *Fumaria parviflora*, *Convolvulus arvensis*, *Cyperus rotundus* and *Cirsium arvense* were found in scanty (Das and Yaduraju, 2002, Pandey, 2002a; Pandey et al., 2002a).

2.2 Crop-weed competition

2.2.1 Crop-weed competition in rice

Rice seedlings emerge five days after sowing, while weed seedlings emerge even earlier indicating a speed in the germination higher than that of rice (Biswas *et al.*, 1992).

During the first 20 days there was less competition between short statured cultivars of rice and weeds. For taller cultivars this period increased to 30 to 40 days. After this, as the rice and weeds grow, competition between them becomes greater (Moody, 1977). Maintaining a weed-free period up to 45 days after planting is essential to augment the yield of medium duration rice (Arokiaraj *et al.*, 1989; Singh *et al.*, 1999b). Weed-free maintenance till 50 days after transplanting was essential and economical, which gave 85% more grain yield over weedy check (Singh, 1992).

One hand weeding or rotary weeding 25 or 40 days after transplanting proved equally effective or even better than most of the herbicides in reducing crop-weed competition (Khare and Jain, 1995; Gogoi, 1997; Gogoi, 1998). Two hand weedings 20 and 40 days after transplanting was as effective as weed free treatment in reducing crop-weed competition and increasing crop yield (Dhiman *et al.*, 1998; Nandal *et al.*, 1999b).

Pandey and Thakur (1988) reported that unchecked weed growth till harvest depleted 35 kg N, 4.3 kg P and 8.2 kg K/ha in addition to 61, 15, 2523 and 166 g/ha each of Zn, Cu, Fe and Mn, respectively. Singh *et al.* (1999b) observed that the N-depletion by weeds was the lowest in weed-free up to 60 days after transplanting. Weeds depleted 35 kg N, 15 kg P₂O₅ and 45 kg K₂O/ha

weeds divested the crop of 43 kg N/ha when allowed to grow unchecked till crop harvest. They also found hand weeding as the most efficient treatment in arresting N drain compared to butachlor and anilofos. Similar were the observations of Choubey *et al.* (1999).

2.2.2 Effect of crop-weed competition on rice yield

Pillai and Rao (1974) reported that due to weeds the yield loss in transplanted rice was 15 to 20%. Moody (1977) observed yield losses up to 60% when *Echinochloa crusgalli* seedlings were transplanted with rice seedlings and not controlled. Dhiman *et al.* (1998) and Gogoi (1998) reported yield reduction due to weed competition by 21 to 47%. Nandal *et al.* (1999b) observed 43% reduction in grain yield as compared to weed-free conditions. Yield loss due to weed competition up to 57% was observed over weed-free conditions by Singh *et al.* (1999). Gopinath and Pandey (2002) reported that weed competition throughout the season reduced the grain yield by 63% compared to two hand weedings. Singh *et al.* (2002c) reported 50% yield loss due to weed competition in rice.

2.2.3 Crop-weed competition in wheat

Phalaris minor was found as the major weed constituting more than 88% of total population in wheat in rice-wheat cropping system (Singh *et al.*, 2002a). It thrives under high fertility and moisture conditions (Singh and Malik, 1992; Singh *et al.*, 1995) and competes vigorously with wheat reducing its yield up to 80% depending upon weed density, cultivation practices and soil and environmental factors. On an average, a population of 200 to 400 plants/m² of *P. minor* was normally observed in field conditions in Haryana and Punjab and its higher

population of 2000 plants/m² resulted in complete crop failure (Malik and Singh, 1995).

Hooda and Agarwal (1991) reported that the population density of *P. minor* and other weeds gradually decreased as irrigation levels increased. Under controlled environmental conditions, water requirement of wheat and *P. minor* was comparable when placed in nutrient solution for two weeks (Singh *et al.*, 1998a).

Singh *et al.* (1984) noted that competition between weeds and wheat was severe up to 80 kg N/ha and it decreased at 120 and 160 kg N/ha owing to reduced weed population and their dry weight due to vigorous crop growth. Uptake of N and K by *P. minor* in wheat was considerably higher compared to broadleaved weeds (Yadav *et al.*, 1986). On an average, uncontrolled weeds 90 days after sowing removed 69, 15 and 52 kg/ha of N, P and K, respectively (Johri *et al.*, 1992) and the uptake of nutrients was greater by grass compared to broad leaved weeds.

Singh and Singh (1996) suggested that one weeding 30 days after sowing was sufficient to produce yields equivalent to two weedings and herbicide application. Hand weeding twice 20 and 40 days after sowing have been found to be effective in reducing crop-weed competition and increasing the yield of wheat at several locations (Singh and Singh, 1996; Singh and Saha, 2001; Pandey *et al.*, 2002b).

2.2.4 Effect of crop-weed competition on wheat yield

Nanda and Patro (1996) reported 50.8% crop yield losses due to weed competition in wheat. Brar *et al.* (1999) observed that uncontrolled weeds

unchecked weed growth in wheat by Das and Kulshrestha (2002) and Mishra *et al.* (2002).

Nepalia and Kanojia (2002) observed 38.7% reduction in yield due to uncontrolled weeds compared to herbicide application. Pandey *et al.* (2002a) observed 34 to 43% yield loss in wheat when weeds were allowed to compete till maturity. Uncontrolled weeds on an average resulted in more than 53% reduction in wheat yield when compared with two hand weedings (Singh *et al.*, 2002a).

A population of 2000 to 3000 plants/m² of *P. minor* were observed in wheat fields in Haryana which resulted in complete crop failure (Malik and Singh, 1995).

2.3 Methods of weed control

2.3.1 Manual weeding

2.3.1.1 Manual weeding in rice

Hand weeding twice in both rice and wheat crops gave highest weed control efficiency and net income over the unweeded control (Sharma and Roy, 1987). Pandey and Thakur (1988) reported that hand weeding resulted in significantly higher yield over other treatments except anilofos + 2,4-D.

Hand weeding was found to be the most effective in arresting weed dry matter accumulation and increasing grain yield compared to butachlor, anilofos, chlorimuron-ethyl and weedy check (Chander and Pandey, 2001). Prasad *et al.* (2001) found two hand weedings more efficient than herbicides in reducing weed growth in rice. Similar was the finding of Gopinath and Pandey (2002). Pandey (2002b) noted significantly higher increase in the grain and straw yields of both rice and wheat with hand weeding compared to herbicides.

In contrast to the above, Nandal *et al.* (1999b) found hand weeding twice 20 and 40 days after transplanting statistically similar to anilofos, butachlor and pretilachlor in increasing grain yield. Similar were the findings of Jayakumar and Anandakrishnan (2001). Rekha *et al.* (2002) also noted identical increase in hand weeding and anilofos + ethoxysulfuron, butachlor and flufenacet. Singh *et al.* (2002) observed higher grain yield with anilofos at 0.4 kg/ha but it was at par with two hand weedings, butachlor and pretilachlor.

2.3.1.2 Manual weeding in wheat

Hand weeding and hand hoeing 4-5 WAS reduced the dry weight of *P. minor* by 38 and 69%, respectively (Sharma *et al.*, 1985). Similarly, Singh and Singh (1996) reported that two weedings (20+40 DAS), pendimethalin and isoproturon were equally effective in reducing weed population and augmenting grain yield. Saini and Singh (2001) found two hand weedings and metribuzin equally effective in increasing grain yield.

Singh and Saha (2001) found highest weed control efficiency with two hand weedings (20 and 40 DAS) and obtained higher grain yield compared to herbicide application. Das and Kulshrestha (2002) also obtained markedly higher grain yield with two hand weedings compared to sulfosulfuron due to significant reduction in weed population.

Pandey (2002a) reported superiority of two hand weedings (20 and 35 DAS) over metribuzin in reducing dry matter accumulation of all types of weeds and concomitant increase in grain yield. Pandey *et al.* (2002b) also found excellent control of weeds with two hand weedings (25 and 45 DAS) resulting in significantly higher grain and straw yields as compared to chlorsulfuron,

2.3.2 Chemical weed control

2.3.2.1 Anilofos

2.3.2.1.1 Effect of anilofos on weeds: Langeluddeke *et al.* (1981) reported that anilofos, at 0.3 to 0.45 kg/ha was effective against annual grasses and sedges. It was found to be effective at 0.3 to 0.6 kg/ha in controlling weeds in transplanted rice (Pandey and Thakur, 1988; Singh and Vaishya, 1994).

Khare and Jain (1995) reported that anilofos at 0.30 to 0.45 kg/ha resulted in weed control efficiency of 84 to 87%. Prasad (1995) observed that anilofos at 0.6 kg/ha reduced the weed dry matter accumulation to the extent of hand weeding. Similar were the findings of Nandal *et al.* (1999b).

At Hisar, anilofos at 0.4 kg/ha caused mortality of *Echinochloa crusgalli* by 95% (Malik and Singh, 1996) and reduced the dry weight by 41 to 62% (Gogoi, 1997). Singh *et al.* (2002d) reported effective control of *Echinochloa crusgalli*, *E. colona* and *Ischaemum rugosum* with anilofos application but there was build up of *Cyperus iria* and *Caesulia axillaris* in continuously anilofos treated plots.

Singh *et al.* (1996) found anilofos as effective as its mixtures with 2,4-D in controlling *Echinochloa* spp. Similarly, Singh *et al.* (1997c) reported that anilofos at 0.4 kg/ha recorded less weed dry weight than its tank mix application with 2,4-D or metsulfuron. Gogoi *et al.* (2000) found butachlor + 2,4-D and anilofos alone equally effective in controlling weeds.

Chander and Pandey (2001) found anilofos at 0.5 kg/ha more effective in arresting dry matter accumulation by weeds compared to butachlor and metsulfuron. A reduction of 63 to 71% in broadleaved weeds and grasses with

anilofos at 0.4 kg/ha was observed by Jayakumar and Anandakrishnan (2001), while 48 to 52% by Singh *et al.* (2002b).

2.3.2.1.2 Effect of anilofos on growth and yield attributes: Munegowda *et al.* (1990) reported some leaf curl and discolouration due to anilofos application at 0.6 kg/ha, but phytotoxicity disappeared with increasing age of the crop and the crop showed no phytotoxicity in freshly emerged leaves. Similar were the findings of Mathew and Jagadeeshkumar (1999). Butachlor and anilofos application had no adverse effect on chlorophyll synthesis of rice plants (Madhu and Nanjappa, 1997).

Gogoi (1997) obtained higher values for yield attributes with anilofos than pretilachlor and weedy check. Nandal *et al.* (1999b) found hand weeding twice, anilofos at 0.4 kg/ha, butachlor at 1.5 kg/ha and pretilachlor at 0.75 kg/ha equally effective in improving yield attributes. Singh *et al.* (1999a) recorded significantly higher number of panicles, panicle length and weight and test weight with pre-emergence application of mixture of anilofos + 2,4-DEE compared to weedy check. Gogoi *et al.* (2000) found butachlor + 2,4-D and anilofos equally effective in improving yield attributes than weedy check. Prasad *et al.* (2001) did not observe significant differences among yield attributes with butachlor and anilofos application. In contrast, significantly higher increase due to them in number of tillers, grain weight/earhead and test weight compared to pretilachlor and weedy check was observed by Gopinath and Pandey (2002).

2.3.2.1.3 Effect of anilofos on yield: Anilofos at 0.3 to 0.6 kg/ha resulted in higher grain yield compared to other herbicides (Jain *et al.*, 1998). Kumar and Basavaraj (1996) found anilofos as effective as weed free treatment in increasing

Gogoi (1997) and Singh *et al.* (1997a) recorded significantly higher grain yield with butachlor and anilofos than pretilachlor and weedy check. Similar was the observation of Gopinath and Pandey (2002). Singh *et al.* (2002) recorded only 54.8 q/ha grain yield with pretilachlor application compared to 62.8 q/ha with anilofos.

Butachlor at 1.0 to 1.5 kg/ha and anilofos at 0.4 to 0.5 kg/ha were found equally effective in increasing grain yield by Pandey *et al.* (1991), Chander and Pandey (2001) and Singh *et al.* (2002).

2.3.2.2 Pretilachlor

2.3.2.2.1 Effect of pretilachlor on weeds: Pretilachlor effectively controlled *Cyperus rotundus*, *Cyperus iria*, *Echinochloa crusgalli*, *Eclipta alba* and *Monochoria vaginalis* (Tewari *et al.*, 1986) and at 1.0 to 1.25 kg/ha markedly lowered dry weight of weeds (Puroshotham *et al.*, 1990; Tomar, 1991; Joy *et al.*, 1992; Kurmi, 1993) and with safener at 0.5 kg/ha reduced density of grass, sedges and broadleaved weeds to the tune of 96.61, 67.51 and 70.71%, respectively (Balasubramanian *et al.*, 1997), while alone at 0.75 kg/ha it scaled down weed density between 15.1 to 50%. Gogoi (1997) and Paradkar *et al.* (1997) found effective control of *Parthenium hysterophorus*, *Echinochloa crusgalli*, *Altermanthera sessilis*, *Corchorus olitorius* and annual sedges in upland rice with its pre-emergence application at 0.75 kg/ha.

Application of pretilachlor through spray or sand mix provided good control of *Echinochloa* sp. (Singh *et al.*, 1997a). Angiras and Rana (1998) found pretilachlor at 0.8 kg/ha as the best treatment for the control of weeds in transplanted rice. Balasubramanian (1998) recorded maximum weed control

caused weed shift from annual to perennial such as sedges. Dhiman *et al.* (1998) also reported that pretilachlor at 0.75 kg/ha resulted in 67 to 86% weed control efficiency. Similar were the findings of Mathew and Jagadeeshkumar (1999).

Pretilachlor at 1.0 kg/ha gave significant control of grasses but was less effective against broad leaved weeds (Phogat and Pandey, 1998). Singh *et al.* (2002d) reported that pretilachlor provided good control of *Echinochloa crusgalli*, *Echinochloa colona* and *Cyperus iria* but could not control *Ischaemum rugosum* and *Caesulia axillaris*.

2.3.2.2 Effect of pretilachlor on growth and yield attributes: Gogoi (1997) reported that herbicides did not cause significant increase in number of tillers and panicles. However, their application resulted in significant improvement in panicle length and grains per panicle. Whereas, Angiras and Rana (1998) and Dhiman *et al.* (1998) observed with pretilachlor (0.80 kg/ha), hand weeding (twice) and butachlor (1.5 kg/ha) significant increase in all the yield attributes.

Pretilachlor at 0.75 kg/ha being at par with butachlor, anilofos and oxyfluorfen recorded significantly lower number of tillers and panicles compared to weed free treatment in late transplanted lowland rice (Gogoi, 1998). Mathew and Jagadeeshkumar (1999) reported that pre-emergence application of herbicide-safener mixtures involving butachlor (1.0 to 1.5 kg/ha) and pretilachlor (0.3 and 0.4 kg/ha) did not have any phytotoxic effect on rice plants, whereas application of herbicides alone exhibited severe phytotoxicity. Nandal *et al.* (1999a) found pretilachlor at 0.75 kg/ha at par with hand weeding twice in respect of yield attributes of transplanted rice. Rajkhowa *et al.* (2001) reported significant increase in panicle number and panicle length due to application of

2.3.2.2.3 Effect of pretilachlor on yield: In transplanted rice, pretilachlor at 0.75 kg/ha, was found effective in suppressing weed growth and augmenting grain yield (Nandal and Singh, 1994a; Phogat and Pandey, 1998; Nandal *et al.*, 1999a). Singh *et al.* (1997a) reported that pretilachlor at 1.5 kg/ha applied through spray or sand mix increased rice yield by 18 to 22% over weedy check. Angiras and Rana (1998) recorded highest grain yield with pretilachlor application compared to butachlor and hand weeding twice.

The grain yield recorded with the pre-emergence application of pretilachlor was significantly similar to that recorded in weed free and other herbicide treatments (Dhiman *et al.*, 1998; Gogoi, 1998). Narayanan *et al.* (2001) recorded highest grain yield with pretilachlor at 0.5 kg/ha. Gopinath and Pandey (2002), however, recorded significantly lower grain yield with pretilachlor application compared to anilofos, butachlor, flufenacet and hand weeding. Singh *et al.* (2002c) also reported lower grain yield with pretilachlor compared to butachlor and anilofos.

2.3.2.3 Flufenacet

2.3.2.3.1 Effect of flufenacet on weeds: Flufenacet (BAY FOE 5043), a new oxyacetamide herbicide was discovered in 1988. In field test, flufenacet in transplanted rice in Indonesia, Korea and Thailand gave very good control of problem grasses and sedges such as *Echinochloa crusgalli*, *Cyperus esculentus*, *Fimbristylis miliacea*, *Scirpus juncooides*, *Leptochloa chinensis* and *Ludwigia octovalvis* when applied at 50 to 120 g/ha. Best results were obtained when applied between 3 and 12 days after transplanting (Deege *et al.*, 1995; Foster *et al.*, 1997). The active ingredient is taken up via the roots and partly via the

germinating shoot. It acts by inhibiting cell division in young root and shoot tissue (Ramsak, 2001).

Although flufenacet controls some dicotyledonous weeds it is primarily a herbicide for the control of annual grasses (Deege *et al.*, 1995). The herbicide mixtures containing flufenacet and metribuzin were found to be more effective in controlling both monocot as well as dicot weeds in soybean, tomatoes and corn (Brinkmann and Dahmen, 1997; Krausz *et al.*, 2000).

Gopinath and Pandey (2002) reported that flufenacet at 100 to 120 g/ha applied 10 days after transplanting (DAT) resulted in significant reduction in weed population and dry weight over weedy check and was comparable with butachlor and anilofos. Similar were the findings of Rekha *et al.* (2002).

2.3.2.3.2 Effect of flufenacet on growth and yield attributes: Application of flufenacet at 100 g/ha 10 DAT resulted in significant improvement in all the yield attributes over pretilachlor and weedy check (Gopinath and Pandey, 2002). Rekha *et al.* (2002) obtained higher values for yield attributes (Effective tillers/m² and grains/panicle) with flufenacet at 90 to 120 g/ha than weedy check.

2.3.2.3.3 Effect of flufenacet on yield: Flufenacet at 200 g/ha was found effective and recorded higher grain yields (DRR, 2000). Its application at 100 and 120 g/ha resulted in significantly higher grain yield compared to its application at 80 g/ha, pretilachlor and weedy check (Gopinath and Pandey, 2002). Rekha *et al.* (2002) also reported that flufenacet at 120 g/ha gave significantly higher grain yield compared to its application at 90 g/ha and weedy check.

2.3.2.4 Sulfosulfuron

2.3.2.4.1 Effect of sulfosulfuron on weeds: Sulfosulfuron differs from other

application at 26 to 35 g ha⁻¹ provided more than 85% control of *Avena fatua*, *Elytrigia repens*, *Bromus secalinus* and *Bromus tectorum* showing little effect on wheat (Hageman *et al.*, 1996). The activity of sulfosulfuron with safener was greatly increased against the resistant biotypes of *Phalaris minor* both in pot and field conditions (Malik and Yadav, 1997). Chauhan *et al.* (1998) reported that sulfosulfuron at 26.6 g/ha was effective against both grass and broad leaved weeds, achieving 90% control of *Phalaris minor*. The sensitivity of selected cereal weeds towards sulfosulfuron was evaluated in a glass house by Loubser (1998). It significantly reduced the dry mass of several dicotyledonous and grass weeds. The affected weed species were *Amaranthus hybridus*, *Cerastium capense*, *Linaria spuria*, *Medicago polymorpha*, *Oxalis pes-caprae*, *Polygonum aviculare* and *Raphanus raphanistrum*. Balyan (1999) found that sulfosulfuron at 20 and 25 g/ha + 0.5% surfactant provided 60 to 90% control of grass weeds and 50 to 60% control of broadleaf weeds. While, Brar *et al.* (1999) reported that sulfosulfuron at 30 and 45 g/ha provided complete control (100%) of resistant *P. minor* in wheat. Pandey (1999) reported that sulfosulfuron gave excellent control of grassy weeds but was not effective against *Chenopodium album* and *Convolvulus arvensis*. Similar was the finding of Sharma *et al.* (1999).

Sulfosulfuron at 25 g/ha resulted in 45 and 49% reduction in the dry weight of *Chenopodium album* and *Rumex retroflex*, respectively (Malik *et al.*, 2000a). With its application 54% control of broadleaf and 70% control of grass weeds was observed by Balyan (2001). Effective control of isoproturon-resistant *P. minor* with sulfosulfuron was reported by Chauhan *et al.* (2001) and Mahajan and Brar (2001). The performance of sulfosulfuron at 25 g/ha was better compared to 20 g/ha and provided good control of both monocot and dicot weeds

(Chhokar *et al.*, 2001b). Saini and Singh (2001), however, reported that sulfosulfuron did not control grass weeds effectively. Das and Kulshrestha (2002) observed that sulfosulfuron gave relatively higher weed control efficiency than recommended dose of isoproturon, clodinafop propargyl and fenoxaprop-p-ethyl.

2.3.2.4.2 Effect of sulfosulfuron on growth and yield attributes: Sulfosulfuron caused slight and temporary growth retardation to wheat at 40 and 50 g/ha. While no reduction in plant height was found at 25 g/ha (Shukla, 1998; Balyan and Singh, 2000). In contrast, Brar *et al.* (1999) reported that even at 45 g/ha sulfosulfuron showed no phytotoxic effect on the wheat crop. Kumar *et al.* (2000) obtained higher values for yield attributes (ear length, number of effective tillers/m and grains/earhead) with sulfosulfuron compared to unweeded check. Similar was the finding of Kumar *et al.* (2001). Das and Kulshtrestha (2002) reported that there was no phytotoxicity of sulfosulfuron on the wheat crop even at the dosage of 75 g/ha.

2.3.2.4.3 Effect of sulfosulfuron on yield: Sulfosulfuron at 20 to 30 g/ha gave significantly higher yield of wheat compared to isoproturon, diclofop-methyl and metoxuron (Shukla, 1998). Application of sulfosulfuron at 25 g/ha increased wheat yield by 42% over two hoeings and 63% compared to weedy check (Brar *et al.*, 1999). Sulfosulfuron at 30 to 33.3 g/ha caused higher increase in yield of wheat compared to other treatments (Sharma *et al.*, 1999; Kumar *et al.*, 2000). In contrast, Malik *et al.* (2000) reported that, due to unsatisfactory weed control, sulfosulfuron at 25 g/ha resulted in significantly poor grain yields of wheat compared to weed free plots. Similar were the findings of Balyan (2001). Sulfosulfuron at 25 g/ha applied one to five days before first irrigation produced

at 20, 40 and 60 g/ha increased significantly the grain and straw yield of wheat compared with weedy check. However, at 60 g/ha marginal reduction in wheat yield was observed compared with lower doses (Kumar *et al.*, 2001). Das and Kulshrestha (2002) reported that sulfosulfuron at 28 g/ha produced highest grain yield compared to isoproturon, fenoxaprop-p-ethyl and clodinafop propargyl.

2.3.2.5 metribuzin

2.3.2.5.1 Effect of metribuzin on weeds: Singh *et al.* (1993) reported effective control of different broadleaf weeds with metribuzin. Metribuzin at 140 and 175 g/ha was effective against both grass and broadleaf weeds, achieving 95 to 98% control of *P. minor* (Chauhan *et al.*, 1998). Balyan *et al.* (1999) observed that metribuzin at 200, 300 and 400 g/ha provided 80 to 98% control of grass weeds and 90 to 95% of broad leaf weeds. Pandey (1999) reported that metribuzin did not kill completely the *Convolvulus arvensis* but arrested its growth till harvest and eliminated *Phalaris minor*, *Avena ludoviciana*, *Melilotus indica* and *Anagallis arvensis*. Singh *et al.* (1999) also found complete control of *P. minor* with metribuzin. Metribuzin (175 g/ha) recorded the lowest population of broadleaf weeds which was significantly superior to diclofopmethyl, 2,4-D and isoproturon + diclofopmethyl (Sardana, 2001a; Sardana *et al.*, 2001).

Metribuzin at 300 g/ha resulted in 82% reduction in weed biomass (Singh *et al.*, 2001b). Das and Yaduraju (2002) concluded that metribuzin at 200 g ha⁻¹ (applied four weeks after sowing using 250 litres of water/ha) may be recommended for broad-spectrum weed control including resistant *P. minor* in wheat. Pandey (2002a) observed that metribuzin applied 35 DAS was better than its pre-emergence application. Pandey *et al.* (2002a) also reported that

metribuzin at 200 g/ha killed all the plants of *Melilotus indica* and gave excellent control of both *P. minor* (98%) and *Avena ludoviciana* (89%).

2.3.2.5.2. Effect of metribuzin on growth and yield attributes: Balyan *et al.* (1997) tested the susceptibility of commonly recommended wheat cultivars to metribuzin and found that all wheat cultivars tested were tolerant to metribuzin at 200 g/ha. However, at 400 g/ha WH 896, WH 147, WH 283 and WH 157 were tolerant while rest of the cultivars were either moderately or highly sensitive. Metribuzin applied at 400 g/ha proved 12.5 to 15% phytotoxic to wheat. The phytotoxicity resulted in the yellowing of wheat, finally significantly reducing wheat tillering which affected the crop yields adversely. But metribuzin at 100 to 300 g/ha did not cause any phytotoxicity to wheat (Balyan and Panwar, 1998; Balyan, 1999). Singh *et al.* (1998b), however, reported that metribuzin at 300 g/ha was effective against *P. minor* but phytotoxic to wheat. Singh *et al.* (1999b) found reduction in the density of wheat crop due to metribuzin at rates higher than 280 g/ha. Reduction in the crop density and wheat spikes increased with the increasing rates of metribuzin.

Saini and Singh (2001) reported that metribuzin at 250 g/ha though controlled all the grassy and broadleaf weeds effectively, caused higher toxicity to the crop and resulted in the lower values of yield attributes (effective tillers/m², grains/spike and 1000-grain weight). Walia *et al.* (2001) also found that wheat crop can tolerate metribuzin only up to 131 g/ha and was phytotoxic to wheat at higher concentrations. Das and Yaduraju (2002) reported that metribuzin at 200 g/ha applied using spray volume of 500 litres/ha was more phytotoxic (42%) to wheat resulting in lower values of yield attributes compared to its application using spray volume of 250 litres/ha. Pandey (2002a) reported that metribuzin at

200 g/ha had detrimental effect on plant height, productive tillers/m, test weight and grain weight/ear compared to metribuzin at 100 and 150 g/ha.

2.3.2.5.3 Effect of metribuzin on yield: Balyan *et al.* (1999) found metribuzin at 200 and 300 g/ha equivalent to weed free treatment in respect to grain yield. However, metribuzin at 400 g/ha registered lower crop yields because of crop phytotoxicity. Pandey (1999) reported that metribuzin at 100 g/ha caused maximum increase in grain yield compared to other herbicides. Singh *et al.* (1999c) recorded higher grain yield with metribuzin at 200 g/ha and isoproturon compared to other herbicides. Sharma *et al.* (1999), however, recorded lower yields with metribuzin at 200 and 250 g/ha compared to tralkoxydim, isoproturon and sulfosulfuron. Similar was the observation of Malik *et al.* (2000b).

Maximum grain yield was obtained with metribuzin at 175 g/ha followed by tank mix application of isoproturon with other herbicides (Sardana, 2001a). In wheat, Sardana *et al.* (2001) reported that isoproturon + 2,4-D at 940 + 500 g/ha resulted in highest grain yield followed by metribuzin at 175 g/ha.

Singh *et al.* (2001a) reported that grain and straw yield of wheat reduced significantly due to application of metribuzin at 200 and 400 g/ha as compared to untreated check. Reduction in yield was compensated to an extent of 12 to 15% at 150 kg seed rate/ha as compared to 100 kg/ha in the plots treated with metribuzin.

Pandey (2002a) found maximum increase in crop yield with metribuzin at 150 g/ha applied as post-emergence compared to its application at 100 and 200 g/ha and as pre-emergence application at all doses. Pandey *et al.* (2002a), however, found metribuzin at 100 g/ha as optimum dose for obtaining higher grain and straw yields compared to metribuzin at 150 and 200 g/ha.

2.4 Residual effect of herbicides

2.4.1 Anilofos

Mishra and Singh (1992) did not find any effect on associated weeds of pea, wheat, gram and lentil due to the herbicides applied to rice. Application of anilofos at 0.6 kg/ha, oxadiazon at 0.5 kg/ha and butachlor at 1.0 kg/ha to transplanted rice and direct sown rice did not show any effect on the performance of succeeding wheat (Nandal and Singh, 1994a and 1994b).

Balasubramanian *et al.* (1999) reported that residues of anilofos, applied at recommended dose continuously for four seasons, in post harvest rice soils were below the toxic level and hence did not influence the germination and yield of blackgram. Janardhan *et al.* (1999) reported that anilofos at 0.4 to 0.6 kg/ha applied to rice had no adverse effect on germination and growth of wheat, peas and cucumber.

Singh *et al.* (2000), however, found that pre-emergence application of anilofos + 2,4-DEE (0.3 + 0.5 kg/ha) supplemented by one hand weeding to rice reduced the population and dry weight of weeds in lentil resulting in significant increase in yield of lentil.

2.4.2 Pretilachlor

Application of butachlor at 1.0 kg/ha and pretilachlor at 0.75 kg/ha to transplanted rice and direct sown rice had no effect on the performance of succeeding wheat (Nandal and Singh, 1994a and 1994b). No adverse effect of thiobencarb, butachlor and pretilachlor applied to rice was observed on weed density and dry matter in succeeding wheat (Singh and Vaishya, 1994). Similar were the findings of Janardhan *et al.* (1999). Pretilachlor applied at the

recommended dose to rice did not show any adverse residual effect on germination and yield of blackgram (Balasubramanian *et al.*, 1999).

2.4.3 Flufenacet

Deege *et al.* (1995) concluded that flufenacet has good toxicological properties and favourable environmental behaviour. Fajardo *et al.* (2000) reported that continuous use of mefenacet did not cause build up of residues and as a result will not be a great threat as an environmental contaminant.

2.4.4 Sulfosulfuron

Sugarbeet (*Beta vulgaris* L.) was severely damaged 53 weeks after treatment with 10 g/ha of chlorsulfuron (Beyer *et al.*, 1988). In green house experiments, sugarbeet, winter rape, sunflower, pea and barley were sensitive to sulfosulfuron (Parrish *et al.*, 1995). Application of sulfosulfuron in autumn wheat at 18, 36 and 72 g/ha reduced seed yield of spring barley and pea by 13 to 59% and 26 to 29%, respectively when these crops followed winter wheat in the rotation (Shinn *et al.*, 1998). Grain sorghum (indicator plant) stem length was reduced even at lower dose (0.025 to 5 ng/g) of sulfosulfuron. Walia *et al.* (2000) observed that growth and development of cucurbits, maize and moong crops were normal when grown in soil collected after the harvest of wheat treated with sulfosulfuron at 25 g/ha. However, sulfosulfuron at 45 g/ha showed phytotoxicity on cucurbits.

2.4.5 Metribuzin

Metribuzin applied at 0.3, 0.6 and 1.3 kg/ha had no carry-over effects on rotational crops spring barley, oats, spring wheat and rapeseed (Conn and Cameron, 1988). Khan and Saghir (1989) found no crop injury to wheat,

soybean, maize and vetch due to metribuzin applied to preceding maize crop at 0.75 to 1.5 kg/ha.

2.5 Persistence of herbicides in soil and crop

2.5.1 Anilofos

Jayakumar and Sreeramulu (1993) reported that anilofos at 0.2 kg/ha was degraded to non-detectable limits within 30 days. However, with higher concentration (0.8 kg), the herbicide persisted until harvest of rice with a half-life of 11 to 15 days. The residues of anilofos and butachlor in rice soil were at non-detectable levels at harvest (Jayakumar *et al.*, 1994). They found no herbicidal residues in grain and straw with lower doses of anilofos (0.75 to 1.0 l/ha) and traces of residues with anilofos at 1.25 l/ha.

Residues of anilofos in soil were degraded within 56 days when applied at 0.2 kg/ha, within harvest at 0.4 kg/ha and beyond harvest at 0.8 kg/ha. The anilofos residues were at detectable levels in rice grain and straw at 0.8 kg/ha of anilofos but were not detectable at 0.2 to 0.4 kg ha⁻¹ (Jayakumar and Sankaran, 1995). Similar were the findings of Radhamani *et al.* (1997) and Balasubramanian *et al.* (1999). Anilofos at 0.4 kg/ha resulted in progressive increase of soil residues over seasons, with 0.079 ppm in first season to 0.1950 ppm in fourth season. Rai *et al.* (1999) reported a half-life of 23 to 77 days for anilofos depending on soil type.

2.5.2 Pretilachlor

Balasubramanian *et al.* (1999) recorded 0.2200 to 0.2920 ppm of pretilachlor residues in soil and 0.0024 to 0.0362 ppm in grain and straw. The half-life of pretilachlor was 7 to 10 days (Fajardo *et al.*, 2000) and there was no

evidence of residue build-up due to continuous application of pretilachlor in the same plot.

2.5.3 Flufenacet

In wheat and in the spring and summer maize crops, the soil half-lives of flufenacet were 98, 74 and 56 days, respectively. At the wheat and maize harvests, flufenacet was not detected in the 0 to 10 and 10 to 15 cm surface soil layers (Rouchaud *et al.*, 1999). Continuous use of both pretilachlor and mefenacet did not cause build up of residues (Fajardo *et al.*, 2000). Gajbhiye and Gupta (2001) reported that soils having low pH, high organic matter and high clay contents showed higher adsorption of flufenacet. They concluded that because of its moderate to high adsorption, flufenacet is likely to persist in soil for some time. However, the possibility of its movement by leaching or surface runoff is less. Rouchaud *et al.* (2001), however, found no relationship between the soil texture and humus concentration in the soil and the persistence of flufenacet in soil.

2.5.4 Sulfosulfuron

Very little information is available on sulfosulfuron as it is a new product. The efforts were, therefore, directed to collect literature and present review on the class as a whole sulfonylurea.

Persistence of sulfonylureas in soil is dependent on pH of the soil. In case of sulfometuron-methyl and metsulfuron-methyl, soil persistence increased with increase in soil pH (Wiese *et al.*, 1988; Walker *et al.*, 1989). Tribenuron-methyl and thifensulfuron-methyl had the shorter persistence than trisulfuron and rarely lasted as residues in sandy and clay soils under temperate climate of Sweden (Nilsson, 1991). Parrish *et al.* (1995) reported that DT₅₀ in soil for sulfosulfuron was in the range of 20 to 60 days.

2.5.5 Metribuzin

Brown *et al.* (1985) reported that half-life of metribuzin in soil was 102 to 112 days. Conn and Cameron (1988) reported that 12% of metribuzin applied still remained in soil 115 days after application. Sorenson *et al.* (1991), however, found that the metribuzin half-life was 4 to 19 days following pre-sowing application and 3 to 17 days following pre-emergence application in soybeans. Kookana *et al.* (1995) also reported that half-life of metribuzin was 27 days. Dubey *et al.* (1998) found no detectable residue (<1 mg/kg) of metribuzin in soil, straw and grain at harvest of crop treated up to 420 g/ha. Johnson (2001) found half-life values of 4.4 to 12.4 days for metribuzin and the half-life of metribuzin was highest for soil under wheat and lowest for soil under clover.

2.6 Residue analysis

2.6.1 Anilofos

Anilofos residues from soil were extracted by shaking with acetone for 30 minutes and from grain and straw with acetone:water (80:20 v/v) mixture. The extracts were analysed by high performance liquid chromatography (HPLC) equipped with UV detector (Sankaran *et al.*, 1993). Quantitatively anilofos residues in soil, grain and straw by gas chromatography (GC) using Flame photometric detector can be analysed with precision.

Jayakumar and Sankaran (1995) extracted anilofos residues in soil, rice grain and straw with acetone:water (80:20 v/v) mixture and detected the residue by HPLC equipped with UV detector. They obtained average recovery greater than 87 per cent with this method. Similarly, Radhamani *et al.* (1997) analysed anilofos residues by HPLC. Balasubramanian *et al.* (1997) analysed herbicide residues in soil, grain and straw of rice by GC equipped with electrone capture

detector (ECD). Rai *et al.* (1999) extracted anilofos residues in soil with ethyl acetate and detected the residue by GC using ECD. They obtained a recovery of 94 to 98 per cent with this method.

2.6.2 Pretilachlor

Residues of pretilachlor from soil and rice straw were extracted by shaking with methanol and from rice grain with acetonitrile. The extracts were purified by partitioning with n-hexane followed by column chromatography using alumina and analysed by GC using ECD (Sankaran *et al.*, 1993). Balasubramanian *et al.* (1999) also determined pretilachlor residues by gas chromatography. Fajardo *et al.* (2000) extracted pretilachlor residues in soil with acetone by shaking for 30 minutes. The extracts were purified by partitioning with hexane and analysed by GC equipped with nitrogen-phosphorus detector (NPD).

2.6.3 Flufenacet

Rouchaud *et al.* (1999) extracted flufenacet residues from soil by stirring with acetone:water (8:2 v/v) mixture. The extract was then purified by thin layer chromatography and analyzed for flufenacet by gas-liquid chromatography (GLC) and combined GC-mass spectrometry (GC-MS). A GLC method for the analysis of residues of flufenacet in soil, water and plant samples was developed by Gajbhiye *et al.* (2000). They extracted residues from soil following single step extraction and clean up procedure and from wheat grain samples in soxhlet extractor with chloroform. Extracts from soil were purified by column chromatography using florisil and grain extracts by partitioning. Samples were finally analysed by GC equipped with ECD. Fajardo *et al.* (2000) extracted mafenacet from soil with acetone. The extracts were partitioned with hexane and

2.6.4 Sulfosulfuron

The thermal lability and low vapour pressure of sulfonyleureas lead to reliance on HPLC method. Selectivity can be improved in several ways including column-switching and selective detectors (Barefoot *et al.*, 1995; Yutai *et al.*, 1999). A reliable method was proposed by Lian *et al.* (1996) for the simultaneous determination of sulfonyleureas in various formulations of commercial products by UV absorption at a wavelength of 254 nm for metsulfuron-methyl, chlorsulfuron and bensulfuron-methyl. Hashimoto *et al.* (1998) reported an analytical method for the determination of tribenuron-methyl and chlorimuron-ethyl in soybean, groundnut and maize by HPLC. The samples were homogenized with acetone and extracted with ethyl acetate. The mobile phase was acetonitrile:water:phosphoric acid (50:50:0.1 v/v). Powley and Bernard (1998) extracted sulfonyleureas residues from soil and water with 0.1 M ammonium carbonate in water:acetone (80:20 v/v). In another method, Turbey *et al.* (1998) extracted soil samples with acetonitrile and 0.2 M ammonium acetate (4;1 v/v) with 0.1% formic acid. This method gave 90 to 95% recovery of sulfosulfuron. Metsulfuron-methyl from soil was extracted by shaking on horizontal shaker using acetonitrile and 2 M ammonium carbonate (100 ml, 9:1 v/v) as extracting solvent. Soil extracts were analysed using HPLC equipped with both UV-VIS detector and on-line radio chemical detector (Yutai *et al.*, 1999).

2.6.5 Metribuzin

Residues of metribuzin were first analysed by Stanley and Schumann (1969). The method employed a single blender extraction, followed by Florisil column cleanup and electron-capture gas chromatographic analysis.

Thornton and Stanley (1977) reported a gas chromatographic procedure for the analysis of metribuzin and its metabolites in a variety of crops. Conjugated residues were released by refluxing the sample. Metribuzin and metabolites were separated by liquid-liquid partition and the two fractions cleaned up individually for electron-capture gas chromatographic analysis. Jarczyk (1983) described a method for the gas chromatographic determination of metribuzin in wheat grain and straw using an N-specific alkali flame ionization detector. Brown *et al.* (1984) extracted metribuzin and bromoxynil octobase and their metabolites from soil with dichloromethane/acetonitrile. Compounds were separated by HPLC (high-performance liquid chromatography) on an octadecyl reverse-phase column with a water/methanol gradient and determined with a variable-wavelength UV detector. Tonogai (1996) extracted five herbicides (metribuzin, propazine, simazine, atrazine and cyanazine) from vegetables and fruits with methanol, re-extracted with 20% ethyl acetate/n-hexane and then cleaned on Sep-Pak silica. Herbicides in cereals and soybeans were extracted with acetonitrile and then cleaned on Sep-Pak silica.

Dubey *et al.* (1998) extracted metribuzin residues from soil samples with methanol:water (4:1 v/v) by stirring for 45 minutes. The extracts were then partitioned with dichloromethane. They also extracted wheat grain and straw samples with acetonitrile. Soil and crop extracts were then analysed using HPLC equipped with 160 selectable wavelength UV detector.

2.7 Economics of herbicide application in rice

In a rice-wheat rotation, hand weeding twice in both crops gave highest net income over the unweeded control. The next highest net income was obtained with two hand weedings in rice followed by isoproturon application and

two hand weedings in wheat (Sharma and Roy, 1987). Similar was the finding of Mandal (1991). Tomar (1987) got highest benefit:cost ratio with pendimethalin at 1 kg a.i./ha. Joy *et al.* (1991) reported that butachlor application resulted in the greatest benefit:cost ratio compared to anilofos, 2,4-D and two hand weedings. Tomar (1991) found two hand weedings as the most cost effective treatment and pretilachlor at 1.25 kg/ha the least in transplanted rice. Joy *et al.* (1992), however, reported that pretilachlor at 0.75 kg/ha and anilofos at 0.4 kg/ha were effective and proved more economical than hand weeding. Janardhan and Muniyappa (1994) also found that anilofos application was the most economical treatment as compared to pretilachlor, 2,4-DEE, pendimethalin and weed-free treatments. Whereas, Nandal and Singh (1994a) reported that net return was highest with pretilachlor application followed by anilofos and butachlor. Gogoi (1997) found pre-emergence application of butachlor and anilofos economical and comparable with hand weeding. Singh *et al.* (2002b) reported that pretilachlor and anilofos application gave a net benefit of Rs 5500-6200 and Rs 3000 – 4800/ha, respectively over the farmers' practice.

2.8 Economics of herbicide application in wheat

Application of fluchloralin recorded the highest net returns followed by pendimethalin and two hand weeding treatments, respectively (Bainade and Patel, 1992). Nandal and Singh (1994a) reported that isoproturon at 1.5 kg/ha proved most economical method of weed management in wheat grown after transplanted rice. Sardana (2001a) got maximum net return with metribuzin at 175 g/ha compared to atrazine, isoproturon, metoxuron and pendimethalin. However, maximum benefit:cost ratio was obtained with atrazine due to its very low cost. Singh and Saha (2001), however, found two hand weedings the most

economical treatment with net returns of Rs 8796/ha compared to chemical weed control. Similar was the finding of Mandal (1991). Singh *et al.* (2001b) reported that application of metribuzin at 300 g/ha contributed the highest rate of increase in the yield of wheat as well as net return over farmer's method.

MATERIALS AND METHODS

The present investigation was carried out during *kharif* and *rabi* seasons of 2000-01 and 2001-02 at the farm of the Indian Agricultural Research Institute (IARI), New Delhi. The details of the materials used and methodology adopted during the course of this study are presented in this chapter.

3.1 Experimental site

The experiment was conducted in the Main Block 14B at the farm of the Division of Agronomy, IARI, New Delhi in both the years.

3.2 Climate and weather conditions

New Delhi is situated at 28°35'N latitude and 77°12'E longitude with an altitude of about 228 m above mean sea level. The climate of the region is semi-arid, sub-tropical with hot summers and cool winters. May and June are the hottest months with the maximum temperature ranging between 41°C and 46°C while January is the coldest month with the minimum temperature approaching 2 to 5°C.

The mean annual precipitation approximate to about 710 mm and is mostly received during a short span of three months between July and September. The winter showers are often accompanied by high wind velocity and hailstorms. The annual pan evaporation is about 850 mm. The mean daily evaporation reaches as high as 16 mm in June and as low as 2.2 mm in January. The relative humidity reaches maximum in January and minimum in March.

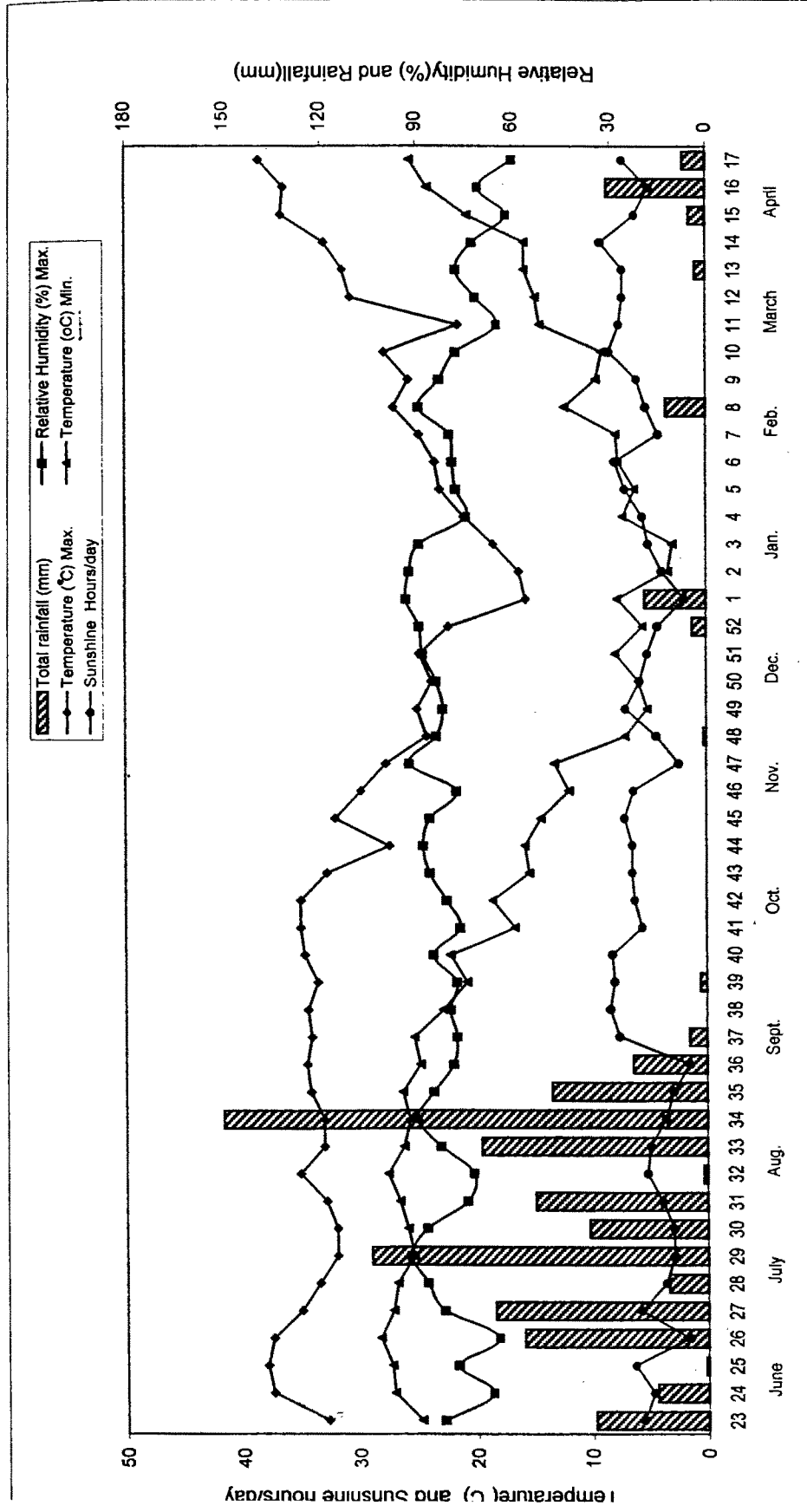


Fig 1. Weekly meteorological data for the crop growth period (2000-01)

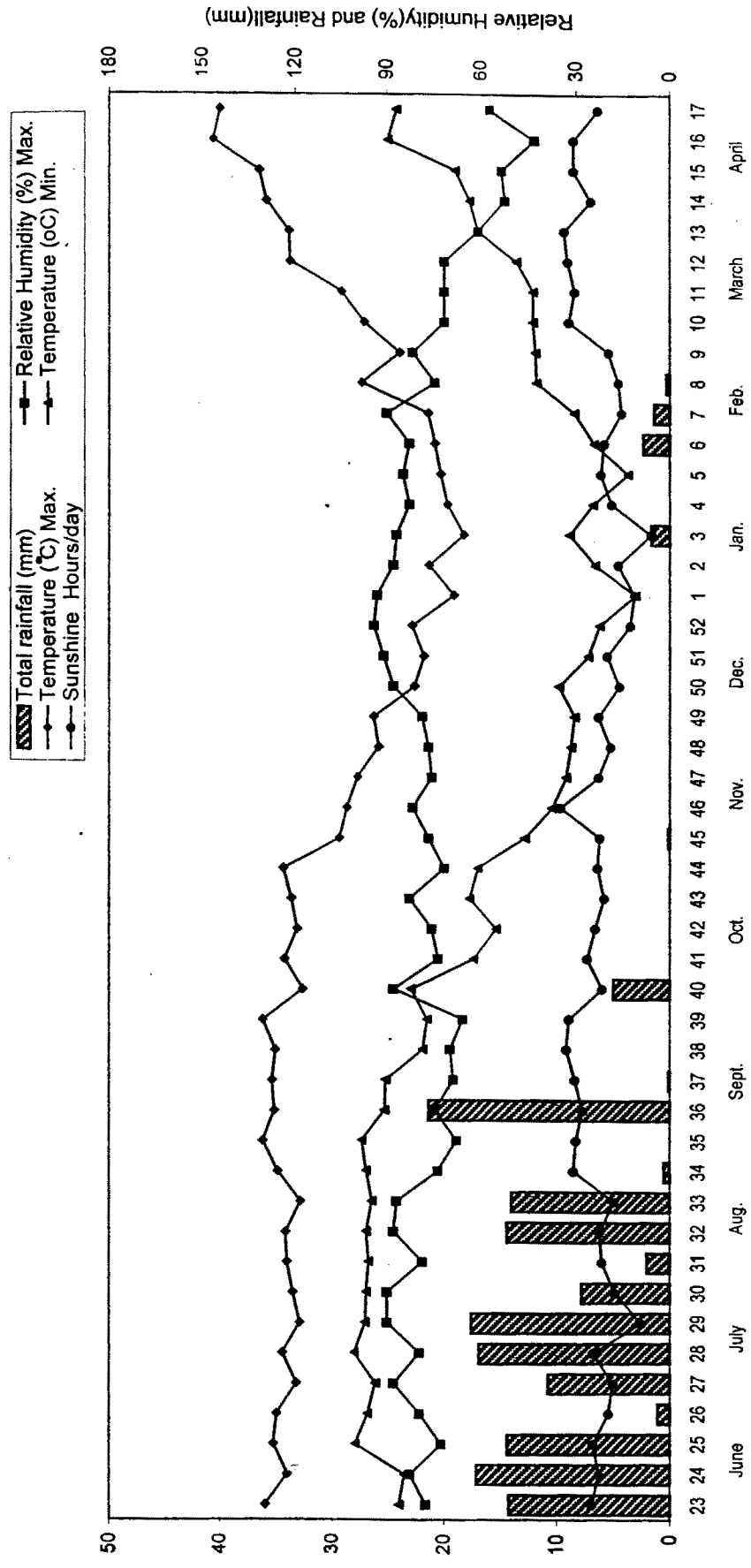


Fig 2. Weekly meteorological data for the crop growth period (2001-02)

Table 1. Mechanical composition and chemical characteristics of soil

Particulars	Main Block 14B		Method used
	2000-01	2001-02	
A. Mechanical composition			
(i) Sand (%)	51.80	52.10	Hydrometer method (Bouyoucos, 1962)
(ii) Silt (%)	23.00	22.70	
(iii) Clay (%)	25.20	25.20	
Textural class	Sandy clay loam		
B. Chemical characteristics			
(i) Organic carbon (%)	0.52	0.54	Walkley and Black method (Jackson, 1973)
(ii) Available N (kg/ha)	188	190	Modified Kjeldahl method (Jackson, 1973)
(iii) Available P (kg/ha)	16.8	17.1	Olsen's method (Jackson, 1973)
(iv) Available K (kg/ha)	215	216	Flame photometer (Jackson, 1973)
(v) pH (Soil to water, 1:2.5)	8.0	8.1	Blackman glass electrode method (Jackson, 1973)
(vi) EC (dS/m at 25°C)	0.58	0.57	Solubridge method (Piper, 1950)

The weather data during the crop growth period, namely *kharif* and *rabi*, 2000-01 and 2001-02, recorded at the Meteorological Observatory, IARI, New Delhi are given in Appendix I and depicted in Fig. 1 and Fig. 2.

3.3 Soil characteristics

The soil is of Yamuna alluvium origin and belongs to order inceptisol, Maharauli series, sandy clay-loam with moderate water holding capacity. The soil of the field was well levelled, slightly alkaline in reaction but deep percolating and well drained. It was medium in organic carbon, available phosphorus and potassium. The mechanical composition and chemical characteristics of the soil of the experimental field are given in Table 1.

3.4 Cropping history of the field

The cropping history of the experimental field is given in Table 2.

Table 2. Cropping history of the field

Year	<i>Kharif</i> (June-Oct.)	<i>Rabi</i> (Nov.-April)
1997-98	Rice	Wheat
1998-99	Rice	Wheat
1999-00	Rice	Wheat
2000-01	Present experiment	Present experiment
2001-02	Present experiment	Present experiment

3.5 Experimental details

3.5.1 Treatments

There were five weed control treatments applied to rice in *kharif* season and four weed control treatments applied to wheat crop in *rabi*. The details of the treatments are given below.

3.5.1.1 *Kharif*

- T₁ : Anilofos at 500 g a.i./ha pre-emergence (pre-em.)
 T₂ : Pretilachlor at 750 g a.i./ha pre-emergence (pre-em.)
 T₃ : Flufenacet at 120 g a.i./ha pre-emergence (pre-em.)
 T₄ : Hand weeding 20 and 40 days after transplanting (DAT)
 T₅ : Weedy check

3.5.1.2 *Rabi*

- W₁ : Sulfosulfuron at 25 g a.i./ha applied 35 days after sowing (DAS)
 W₂ : Metribuzin at 200 g a.i./ha applied 35 days after sowing (DAS)
 W₃ : Hand weeding 30 and 45 days after sowing (DAS)
 W₄ : Weedy check

3.5.2 Experimental design and layout

3.5.2.1 Design

The experiment was laid out in an extended group design (rectangular design). Twenty treatment combinations were obtained from five *kharif* and four *rabi* treatments. These 20 treatment combinations were arranged in six blocks each of size 10 plots. The block contents are given in Fig. 3.

3.5.2.2 Layout

The plan of layout of the experiment is depicted in Fig. 3.

- Number of treatments : (i) *Kharif* : 5
 (ii) *Rabi* : 4
- Number of blocks : 6
- Total number of plots : 60
- Gross plot size : (i) *Kharif*: 5 m x 2 m (10 m²)
 (ii) *Rabi*: 5 m x 1.98 m (9.9 m²)

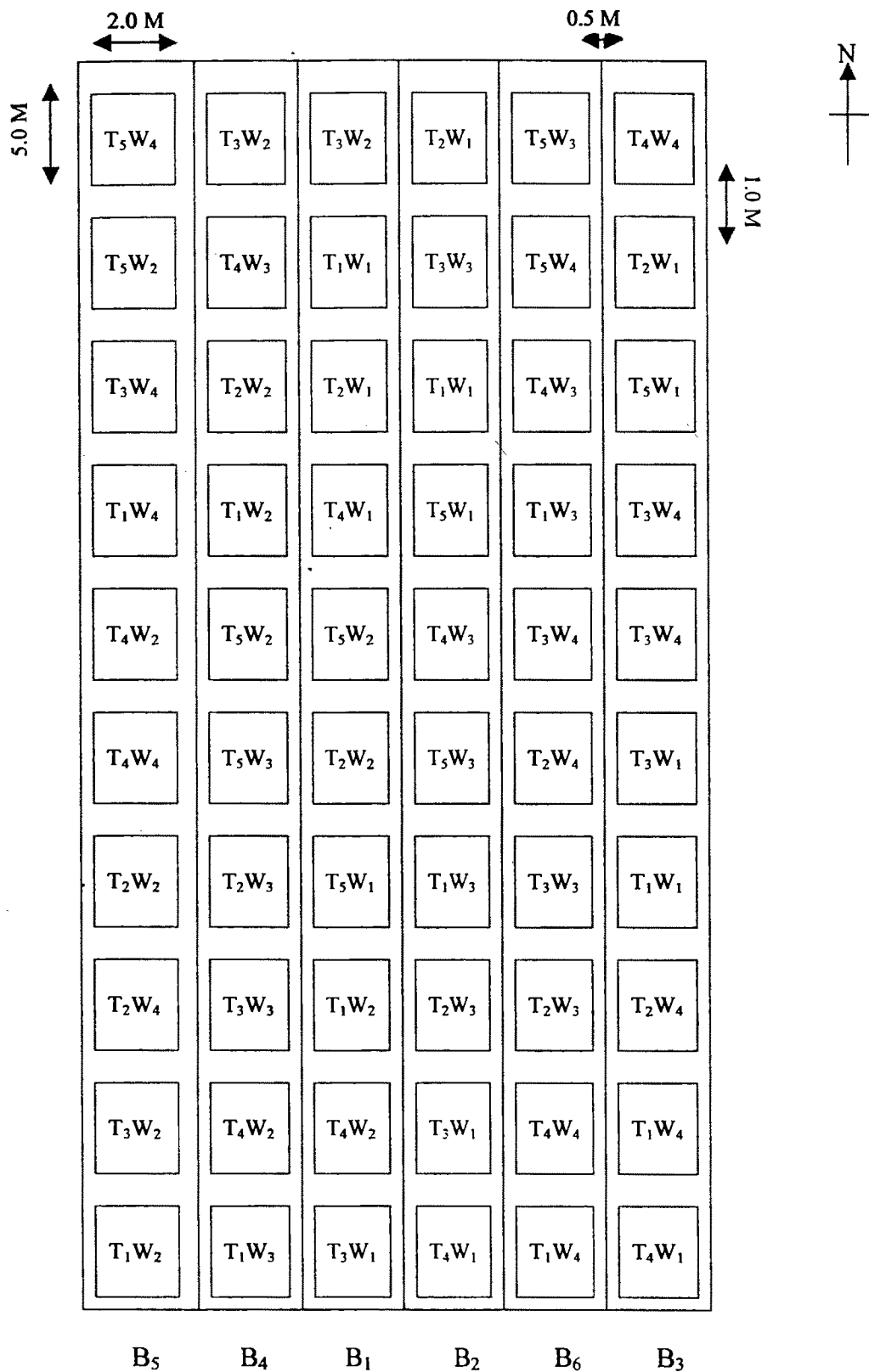


Fig 3. Plan of experimental layout

Treatments:

Kharif (Rice)

- T₁: Anilofos 500 g/ha
- T₂: Pretilachlor 750 g/ha
- T₃: Flufenacet 200 g/ha
- T₄: Hand Weeding (20 and 40 DAT)

Rabi (Wheat)

- W₁: Sulfosulfuron 25 g/ha
- W₂: Metribuzin 200 g/ha
- W₃: Hand Weeding (30 and 45 DAS)
- W₄: Weedy Check

Net plot size : (i) *Kharif*: 4 m x 1.2 m (4.8 m²)
(ii) *Rabi*: 4 m x 1.1 m (4.4 m²)

Spacing for rice : 20 cm x 10 cm

Spacing between rows of wheat: 22 cm

3.6 Description of crop varieties used

3.6.1 Rice (Pusa 44)

It was developed at IARI, New Delhi and was released for general cultivation in 1994 for northern India. Plants are semi-dwarf with a height of about 100 cm and highly resistant to lodging. It produces medium slender and non-aromatic seeds. It matures in about 135-145 days and its yield potential is 50-100 quintals per hectare.

3.6.2 Wheat (HD 2285 or Govind)

It was developed at IARI, New Delhi from a cross 249/HD 2160/HD 2186 and was released for general cultivation in 1983 for north-western and north-eastern plain zones. It is suitable for late sown and very late sown conditions in irrigated areas. It is a double dwarf with a height of about 90 cm, early maturing (108-121 days) and resistant to rusts and karnal bunt. It also possesses terminal heat tolerance and wider adaptability. Grains are amber, hard, medium bold and makes good chapatis. It fits well in intensive cropping system.

3.7 Field operations

The details of field operations carried out during the crop seasons are given in appendix 2 and the main operations are described below.

3.7.1 Raising of rice nursery

The nursery was grown on puddled raised beds of 10 m x 1 m leaving

of 250 g of urea, 300 g of single superphosphate and 100 g of muriate of potash were applied to each 10 m² bed. Sprouted seeds were broadcast uniformly on the wet nursery at the rate of 300 g per bed. The beds were irrigated regularly. Fifteen days after sowing, one manual weeding was given and 250 g urea was applied to each bed. The seedlings were grown to an age of 25 to 30 days for transplanting.

3.7.2 Land preparation

The experimental field was ploughed deeply followed by discing. Puddling was done with a puddler in flooded field and field was finally leveled. Bunds were erected around each plot before transplanting. After harvesting of rice, the field was prepared for sowing wheat without disturbing the original layout. The site of experiment was shifted in the second year to adjacent field.

3.7.3 Crop establishment

For rice, two to three 25 to 30 days old seedlings were transplanted per hill at a spacing of 20 cm x 10 cm. The seed rate for wheat was 100 kg/ha. For sowing wheat, a tractor drawn seed drill with row to row spacing of 22 cm was used.

3.7.4 Gap filling and thinning

A week after transplanting of rice, gap filling was done wherever necessary. After recording germination count for wheat, gap filling by resowing and thinning was done where required.

3.7.5 Fertilizer application

A fertilizer dose of 100 kg N, 60 kg P₂O₅ and 40 kg K₂O/ha was used for rice. Full quantity of P and K and half of nitrogen was applied as basal and remaining N was applied 40 DAT.

In wheat, 120 kg N, 60 kg P₂O₅ and 40 kg K₂O/ha was used. Full quantity of P and K and half of nitrogen was applied as basal and remaining N in two equal splits 30 and 60 DAS. Sources of nitrogen, phosphorus and potassium were urea (46% N), single superphosphate (16% P₂O₅) and muriate of potash (60% K₂O), respectively.

3.7.6 Irrigation

Required irrigations were given to maintain 3-5 cm standing water in the rice field. Besides rainfall, water was supplied through irrigation system to meet the demand of wheat for normal growth.

3.7.7 Manual weeding

Two hand weedings were done at 20 and 40 days by manually uprooting the weeds in the rice plots under hand weeding. In wheat two hand weedings were given 30 and 45 DAS with the help of *khurpi* as per treatments.

3.7.8 Herbicide application

Anilofos and pretilachlor were sprayed, as per treatments, with knapsack sprayer using 600 liters of water/ha. Flufenacet was mixed with sand at 50 kg/ha and uniformly broadcasted as per treatment. All the three herbicides were applied 3 DAT of rice.

In wheat sulfosulfuron and metribuzin were sprayed with knapsack sprayer using 600 litres of water/ha 30 DAS as per treatments.

3.7.9 Plant protection measures

Endosulfan at 3 ml/l of water was sprayed to protect the rice crop from stem borer. No pesticide was sprayed in wheat as there was no infestation of the crop either by insects or diseases.

3.7.10 Harvesting and threshing

Crops of the system were harvested manually when all the panicles/spikes turned yellow. The net plots after removing the border rows were harvested and left in the respective plots for drying. The dried crop was tied into bundles plotwise separately, labeled and weight of each bundle was recorded separately before threshing. Both the crops were threshed with the help of power drawn thresher.

3.8 Details of data collection

3.8.1 Observations on weeds

3.8.1.1 Weed population: An area of 0.25 m² was selected randomly by placing a quadrat of 50 cm x 50 cm. Weeds were counted individually from the quadrat area. The data thus obtained were expressed in number of plants/m².

3.8.1.2 Weed dry matter: Weeds from 0.25 m² area from each plot were removed and dried under the sun. These were then oven dried at 70°C to a constant weight. Finally the dry weight was recorded and expressed in g/m².

3.8.1.3 Weed index (WI): Weed index (%) was calculated from the grain yields of rice and wheat by using the formula suggested by Rathore *et al.* (1990) as:

$$WI (\%) = \frac{\text{Yield of treated plot} - \text{Yield of control plot}}{\text{Yield of treated plot}} \times 100$$

3.8.1.4 Weed control efficiency (WCE): Weed control efficiency (%) of different weed control treatments was calculated from the data on weed dry weight by using the formula:

$$WCE (\%) = \frac{\text{Weed dry weight in control plot} - \text{Weed dry weight in treated plot}}{\text{Weed dry weight in control plot}} \times 100$$

3.8.2 Observations on crops

3.8.2.1 Plant population: Plant population of wheat per running metre was recorded from two different rows in each plot to study the residual effect of herbicides. Observations were taken before gap filling and thinning.

3.8.2.2 Plant height: Height of five plants randomly selected from each plot was measured in cm from base level to the tip of the largest leaf, while after flowering the top of the panicle/ear was taken as upper limit. The mean values were then computed.

3.8.2.3 Tiller number: Number of tillers per hill for the five sample plants were counted and average number of tillers per hill were computed.

In wheat, number of tillers per running metre was recorded at 60 and 90 DAS from two different rows in each plot and expressed as tillers per metre row length.

3.8.2.4 Dry matter accumulation: Five rice hills were randomly collected by cutting at ground level. In wheat, one metre row length was selected randomly from the second row of each plot and plants were cut at ground level. The removed plants were dried under the sun and later oven dried at 65-70°C for 48 hours before final weighing. Dry matter was expressed as g/hill and g/metre row length in rice and wheat, respectively.

3.8.2.5 Number of effective tillers: Number of effective tillers (bearing panicles/ears) per hill of rice and per metre row length in wheat were counted at harvest.

3.8.2.6 Panicle and ear length: Length of five panicles/ears per plot selected randomly at the time of harvesting was recorded and average values were expressed in cm.

3.8.2.7 Grain weight per panicle and ear: From the randomly selected panicles/ears, grains were separated manually, weighed and mean grain weight was computed.

3.8.2.8 Test weight: Thousand grains were counted manually from the harvested and cleaned produce of each plot and their weights were recorded.

3.8.2.9 Grain yield: The weight of grains obtained from each net plot was recorded and expressed as q/ha.

3.8.2.10 Straw yield: Straw yield was obtained by subtracting grain yield from total biomass yield of each plot. The yield was expressed in q/ha.

3.8.2.11 Harvest index: The harvest index was calculated by the formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (q/ha)}}{\text{Biological yield (q/ha)}} \times 100$$

3.9 Herbicide residue estimation (*kharif* season)

Soil samples (15 cm depth) were collected from herbicide treated and untreated field plots in each Block, at two times, on the day of herbicide application and at rice harvest. The samples were mixed thoroughly and extracted on the same day of collection. In *rabi*, soil samples were collected, at two times, on the day of herbicide application and at harvest of wheat. The samples were mixed thoroughly, air dried and passed through 2 mm sieve.

3.9.1 Extraction

3.9.1.1 Soil

3.9.1.1.1 Anilofos, pretilachlor and flufenacet: Soil samples (100 g soil) were transferred to Erlenmeyer flasks (500 ml). Acetone (200 ml) was added to each flask, stoppered, shaken vigorously for few minutes and kept overnight. The clear supernatant was decanted. The residue soil samples were further extracted two

more times with 100 ml of acetone each time by shaking on a mechanical shaker for 30 minutes. The combined supernatant was concentrated till acetone was removed. The aqueous extract was transferred to separatory funnel (500 ml) and diluted with 100 ml of 2% sodium chloride solution. The aqueous phase was extracted by partitioning thrice with chloroform (3 x 50 ml). The chloroform extract was passed through anhydrous sodium sulfate to remove traces of moisture and concentrated to dryness. The traces of chloroform were removed by adding 5 ml hexane and evaporating it completely. Finally the residues were dissolved in hexane for analysis.

3.9.1.2 Rice grain

3.9.1.2.1 Anilofos: Finely ground samples of grain (50 g) were transferred to Erlenmeyer flask (250 ml) with 150 ml of acetone/water (80:20) mixture and extracted by shaking on a mechanical shaker for 30 minutes. The extract was passed through Whatman No. 1 filter paper. The extraction was done twice more with same solvent system 100 ml each time.

The combined filtrate was concentrated to about 50 ml, transferred to a separatory funnel and diluted with 100 ml of 2% aqueous sodium chloride solution. The aqueous phase was partitioned thrice with dichloromethane (3 x 50 ml). The combined dichloromethane layer was dried by passing through anhydrous sodium sulfate in order to make it free from traces of water and concentrated to near dryness.

3.9.1.2.2 Pretilachlor: Acetonitrile and methanol (100 ml) as added to powdered grain (50 g) samples and left overnight. The contents were shaken for two hours with a mechanical shaker. The slurry was filtered through a fluted filter paper.

The combined filtrate was concentrated to about 50 ml. The concentrated extract from grain was transferred to a 250 ml separatory funnel and the acetonitrile solution was extracted twice with 50 ml of n-hexane and the n-hexane is discarded. The residues were re-extracted from the acetonitrile phase after addition of 100 ml of sodium chloride solution with three 100 ml portions of n-hexane by vigorously shaking for at least two minutes during each extraction. The n-hexane phases were collected, passed through anhydrous sodium sulfate and evaporated to dryness.

3.9.1.2.3 Flufenacet: The powdered grain (10 g) sample was taken in a filter paper thimble and extracted in soxhlet extractor with 250 ml of chloroform for 4 hours. The chloroform from the extract was distilled off completely. The residues were dissolved in acetonitrile (50 ml) and transferred quantitatively to separatory funnel (250 ml). The acetonitrile phase was partitioned three times with hexane (30 ml) and the hexane phase was discarded. The acetonitrile phase was then diluted five times with saturated sodium chloride solution and partitioned thrice with chloroform (50 ml). The traces of moisture from chloroform extract were removed by passing it through anhydrous sodium sulfate and concentrated. The traces of chloroform were removed by adding 5 ml of hexane and evaporating it completely. Finally the residues were dissolved in hexane for analysis.

3.9.2 Clean-up

There was no additional clean-up required for soil and grain extracts.

3.9.3 Estimation

The residues of anilophos, pretilachlor and flufenacet were analysed on Hewlett Packard 5890 Series II gas chromatograph equipped with ⁶³Ni electron capture detector (ECD). auto injector 7673, megabore HP-1 column (10 m x 0.53

mm i.d.). The operating parameters were: column, injector and detector temperatures were 200, 220 and 240°C, respectively for anilofos and pretilachlor estimation. For flufenacet, detector and injection port temperatures were 300 and 280, respectively and column temperature was programmed at 160°C for 9 minutes then raised to 260°C at 30°C/min and maintained for 3 minutes. Nitrogen was used as carrier gas (LIOLAR 1) with flow rate of 15 ml/min for estimation of all the three herbicides.

3.10 Herbicide residue estimation (*Rabi* season)

3.10.1 Extraction

3.10.1.1 Soil

3.10.1.1.1 Sulfosulfuron: Soil sample (50 g) was taken in an Erlenmeyer flask (250 ml) and 100 ml of a mixture of acetonitrile:1M ammonium carbonate solution (90:10 v/v) was added. The flask was stoppered and shaken on a mechanical shaker for 30 minutes. The contents were allowed to settle and supernatant phase was filtered through Buchner funnel using water pump. The extraction was done twice more with same solvent system (80 ml) and filtered in the same way. The combined filtrate was concentrated to about 20 ml. The concentrated extract was transferred to a 250 ml separatory funnel, diluted with 100 ml of distilled water and partitioned thrice with dichloromethane (50 ml). The dichloromethane layer was passed through anhydrous sodium sulfate to remove traces of moisture and evaporated to dryness.

3.10.1.1.2 Metribuzin: To the soil sample (25 g) in an Erlenmeyer flask (250 ml), 200 ml of a mixture of methanol:water (4:1 v/v) was added. The flask was stoppered and shaken on a mechanical shaker for 45 minutes. The clear supernatant was decanted. The residue soil sample was further extracted twice

with 100 ml of acetonitrile and the supernatant decanted. The combined supernatant was concentrated and partitioned thrice with dichloromethane (50 ml). The dichloromethane layer was passed through anhydrous sodium sulfate to remove traces of moisture and evaporated to dryness.

3.10.1.2 Wheat grain

3.10.1.2.1 Sulfosulfuron: The powdered grain sample (50 g) was taken in a filter paper thimble and extracted in soxhlet apparatus with 250 ml of acetone for four hours. The extract was concentrated to about 10 ml. The concentrated extract was transferred to a separatory funnel (250 ml), diluted with 100 ml of water and partitioned twice with dichloromethane (50 ml). The dichloromethane layer was passed through anhydrous sodium sulfate and evaporated to dryness.

3.10.1.2.2 Metribuzin: To the powdered grain sample (10 g), 100 ml of acetonitrile was added and left overnight. The contents were shaken on a mechanical shaker for 30 minutes and the slurry was filtered through a filter paper. The extract was concentrated to dryness and dissolved in HPLC grade acetonitrile for chromatographic analysis.

3.10.2 Clean-up

There was no additional clean-up required for soil and grain extracts.

3.10.3 Estimation

3.10.3.1 Sulfosulfuron: The residues of sulfosulfuron were analysed on Hewlett Packard HPLC instrument (Series 1100) equipped with degasser, quaternary pump and diode-array detector. The stationary phase consisted of Lichrospher Ion RP-8 packed stainless steel column (250 mm x 4 mm i.d.). The stationary phase consisted of Lichrospher Ion RP-8 packed stainless steel column (250 mm x 4 mm i.d.). Acetonitrile:water:0-phosphoric acid (80:20:0.1) mixture was used

as mobile phase at a flow rate of 1 ml/min. Injection volume of sample was 10 μ l.

The detector was set at 212 nm.

3.10.3.2 Metribuzin: A Hewlett Packard HPLC instrument (Series 1100) equipped with degasser, quaternary pump, 160 selectable wavelength UV detector and ultrasphere ODS (C-18), 4.6 mm i.d. x 15 cm analytical column. The mobile phase used consisted of mixture of acetonitrile:water (30:70, v/v) at a flow rate of 1 ml/min. Injection volume of sample was 10 μ l. The detector was set at 229 nm.

3.10 Economics

Cost of cultivation and gross return for each treatment was worked out on the basis of the prevailing market price for input and the produce (grain and straw). The details are given in appendices III and IV. The net return per hectare was calculated by deducting the cost of cultivation from gross return.

Gross return (Rs/ha) = Price of grain + Price of straw

Net return (Rs/ha) = Gross return (Rs/ha) – Cost of cultivation (Rs/ha)

Net return per rupee invested = $\frac{\text{Net return (Rs/ha)}}{\text{Cost of cultivation (Rs/ha)}}$

Additional return due to weed control (Rs/ha) = $\frac{\text{Gross return from the treatment} - (\text{Gross return from weedy check} + \text{Cost of weed control})}{\text{Cost of weed control}}$

Additional return per rupee invested = $\frac{\text{Additional return due to weed control}}{\text{Cost of weed control}}$

3.11 Statistical analysis

The *kharif* data were analysed as a general block design where each treatment was replicated twice in each block. The *rabi* data were analysed as per procedure of block designs with factorial structure. Details on the analytical aspects are given in Prasad *et al.* (2000) and Gupta and Mukherjee (1989).

RESULTS

The experimental results obtained during the present study are presented in this chapter. The data are presented in Tables 3 to 33. Data on some important parameters are also depicted in Figures 4 to 11.

4.1 Rice

4.1.1 Observations on weeds

4.1.1.1 Weed flora

In both the years, weed species in the experimental plot consisted of a mixed population of grass (80.9%) and broadleaf weeds (19.1%). *Echinochloa crusgalli* (35.8%) and *Echinochloa colona* (23.3%) were the predominant weeds among the grasses which together constituted 50.1% of total weed population while *Eclipta alba* (12%) and *Oxalis corniculata* (4.2%) were dominant among broadleaf weeds. Besides, *Leptochloa chinensis*, *Paspalum scrobiculatum*, *Cynodon dactylon*, *Digitaria ciliaris*, *Commelina benghalensis* and *Cyperus rotundus* were also present in small numbers.

4.1.1.2 Weed population

Data on specieswise weed population recorded 30 and 60 days after transplanting (DAT) and at harvest are presented in Tables 3, 4 and 5.

4.1.1.2.1 *Echinochloa crusgalli*: Weed control treatments brought about marked reduction in the population of *E. crusgalli* compared to weedy check in both the years. At 30 days stage in both the years, maximum reduction in its population was in flufenacet. It was at par with anilofos and two hand weeding

2000, in anilofos and flufenacet significantly lower number was recorded compared to other treatments (Table 4) while in 2001, in the latter compared to all other treatments except two hand weedings (Table 4). At harvest, in 2000, population in flufenacet and hand weeding was similar but significantly lower compared to other treatments except anilofos (Table 5). In 2001, flufenacet application resulted in drastic decrease and proved significantly superior to other treatments (Table 5).

4.1.1.2.2 *Echinochloa colona*: In 2000, at all the growth stages, population of *E. colona* was similar in flufenacet, anilofos and hand weeding which was significantly lower compared to other treatments. While in 2001, at 30 days stage, flufenacet resulted maximum decrease and was significantly superior to other treatments (Table 3). Anilofos and hand weeding being at par were the next best treatments. Similarly, at 60 days stage, significantly lower number was recorded in flufenacet compared to other treatments (Table 4). Anilofos application was the next best treatment. At harvest, in 2001, in flufenacet the lowest population was recorded but was at par with anilofos and hand weeding. However, it proved significantly superior to pretilachlor and weedy check in lowering the population (Table 5).

4.1.1.2.3 Grass weeds: Weed control treatments brought about significant reduction in the population of grass weeds compared to weedy check in both the years. At 30 days and at harvest stages, flufenacet application resulted in the maximum reduction of grass weeds and proved significantly superior to all other treatments in both the years except hand weeding in 2000. Pretilachlor was least effective among the herbicides on grass weeds which, however, recorded

significantly lower number compared to weedy check. Similarly, at 60 days stage, flufenacet caused significantly higher reduction compared to all other treatments in both the years except anilofos in 2000 (Table 4). In anilofos and hand weeding number of grass weeds was almost similar but significantly lower than weedy check.

4.1.1.2.4 Broadleaf weeds: At 30 days stage in 2000, anilofos application brought about significant reduction in the population of broadleaf weeds compared to other treatments except hand weeding (Table 3). But in 2001, in hand weeding significantly lower population was recorded compared to other treatments (Table 3). Flufenacet, which gave excellent control of grass weeds, was comparatively less effective on broad leaf weeds. At 60 days stage in both the years hand weeding was most effective in lowering the population of broadleaf weeds (Table 4) and proved significantly superior to all other treatments except anilofos in 2001. Pretilachlor was the least effective herbicide against broadleaf weeds. At harvest in 2000, the lowest population was recorded in hand weeding and it proved significantly superior to other treatments except anilofos (Table 5). However, in 2001, all the weed control treatments caused similar reduction and were statistically superior to weedy check (Table 5).

4.1.1.2.5 Total weeds: Weed control treatments effected significant reduction in the total weed population compared to weedy check in both the years. In 2000, 30 DAT, anilofos, flufenacet and hand weeding caused similar reduction and proved significantly superior to pretilachlor (Table 3). However, in 2001, significantly lower population was recorded in flufenacet (Table 3) compared to other treatments. In 2000, significantly lower population was recorded in hand

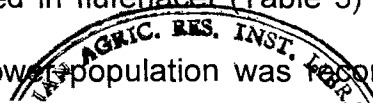


Table 3. Effect of treatments on weed population per m² in rice (30 DAT)

Treatment	<i>E. crusgalli</i>		<i>E. colonum</i>		Grass weeds		Broadleaf weeds		Total weeds	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Anilofos 500 g/ha	1.6 (2.2)	2.1 (4.1)	1.7 (2.5)	1.9 (3.2)	2.9 (8.1)	3.2 (10.1)	2.3 (4.8)	2.5 (6.1)	3.6 (12.9)	4.1 (16.2)
Pretilachlor 750 g/ha	2.8 (7.6)	3.0 (8.5)	2.2 (4.3)	2.6 (6.3)	4.1 (16.3)	4.6 (21.2)	2.9 (8.0)	3.2 (9.8)	4.9 (24.3)	5.6 (31.0)
Flufenacet 120 g/ha	1.5 (1.8)	1.8 (2.9)	1.5 (1.8)	1.2 (1.0)	2.6 (6.3)	2.6 (6.4)	2.7 (6.8)	2.5 (6.1)	3.7 (13.1)	3.6 (12.5)
Hand weeding	1.8 (2.8)	2.1 (4.0)	1.6 (2.1)	2.2 (4.4)	2.8 (7.5)	3.6 (12.5)	2.5 (6.0)	2.2 (4.3)	3.7 (13.5)	4.1 (16.8)
Weedy check	5.4 (29.0)	5.9 (34.6)	4.1 (16.5)	4.8 (23.1)	7.9 (61.6)	8.3 (68.6)	3.6 (12.5)	3.8 (14.0)	8.6 (74.1)	9.1 (82.6)
SEm +	0.14	0.14	0.10	0.13	0.09	0.10	0.10	0.09	0.10	0.10
CD (P=0.05)	0.40	0.40	0.28	0.37	0.25	0.28	0.28	0.25	0.28	0.28

Figures in parentheses indicate original values

e 4. Effect of treatments on weed population per m² in rice (60 DAT)

Treatment	<i>E. crusgalli</i>		<i>E. colonum</i>		Grass weeds		Broadleaf weeds		Total weeds	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
ifos 500 g/ha	1.9 (3.3)	2.4 (5.5)	1.8 (3.0)	2.2 (4.8)	3.3 (10.8)	4.2 (17.2)	2.4 (5.6)	2.6 (6.3)	4.1 (16.4)	4.9 (23.5)
lachlor 750 g/ha	3.1 (9.0)	2.8 (7.6)	2.8 (7.5)	2.7 (6.8)	4.8 (22.6)	4.8 (23.0)	3.5 (11.8)	3.9 (15.0)	5.9 (34.4)	6.2 (38.0)
anacet 120 g/ha	1.6 (2.2)	1.9 (3.2)	1.7 (2.4)	1.6 (2.2)	3.1 (9.3)	3.3 (10.4)	3.1 (9.2)	3.1 (9.1)	4.3 (18.5)	4.5 (19.5)
d weeding	2.4 (5.6)	2.1 (4.1)	1.9 (3.4)	2.7 (6.8)	3.5 (12.0)	4.2 (17.2)	2.0 (4.0)	2.4 (5.8)	4.0 (16.0)	4.8 (23.0)
dy check	5.5 (30.0)	6.1 (37.2)	4.5 (19.8)	4.9 (23.8)	8.4 (70.5)	9.0 (81.1)	4.3 (18.5)	4.2 (17.4)	9.4 (89.0)	9.9 (98.5)
1 +	0.13	0.14	0.12	0.15	0.08	0.09	0.10	0.10	0.09	0.15
(P=0.05)	0.37	0.40	0.34	0.43	0.22	0.25	0.28	0.28	0.25	0.43

ires in parentheses indicate original values

Table 5. Effect of treatments on weed population per m² in rice (at harvest)

Treatment	<i>E. crusgalli</i>		<i>E. colonum</i>		Grass weeds		Broadleaf weeds		Total weeds	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Anilofos 500 g/ha	1.4 (1.6)	1.5 (1.9)	0.8 (0.2)	1.0 (0.7)	2.2 (4.4)	2.5 (6.1)	2.3 (5.1)	2.6 (6.3)	3.1 (9.5)	3.5 (12.4)
Pretilachlor 750 g/ha	1.6 (2.2)	1.7 (2.5)	1.2 (1.0)	1.2 (1.0)	2.3 (5.1)	3.0 (8.7)	3.1 (9.5)	2.5 (5.9)	3.9 (14.6)	3.9 (14.6)
Flufenacet 120 g/ha	1.2 (1.0)	0.8 (0.2)	0.9 (0.4)	0.9 (0.3)	1.9 (3.1)	1.9 (3.1)	2.6 (6.5)	2.7 (6.7)	3.1 (9.6)	3.2 (9.8)
Hand weeding	1.2 (1.1)	1.2 (1.0)	0.9 (0.4)	1.1 (0.8)	2.1 (4.0)	2.5 (5.8)	2.1 (4.0)	2.5 (5.8)	2.9 (8.0)	3.4 (11.6)
Weedy check	2.1 (4.1)	2.7 (7.2)	1.6 (2.1)	1.9 (3.3)	4.9 (23.7)	5.2 (27.2)	4.6 (21.0)	5.0 (25.0)	6.7 (44.7)	7.2 (52.2)
SEM +	0.08	0.10	0.08	0.09	0.09	0.11	0.12	0.14	0.10	0.11
SD (P=0.05)	0.22	0.28	0.22	0.25	0.25	0.31	0.34	0.40	0.28	0.31

Figures in parentheses indicate original values

weeded plots compared to other treatments except anilofos at 60 days stage (Table 4) and anilofos and flufenacet at harvest (Table 5). Population in latter two treatments was almost similar. In 2001, both at 60 days and at harvest stages, the lowest population was recorded in flufenacet which was at par with anilofos and hand weeding (Tables 4 and 5). Pretilachlor was least effective among the weed control treatments.

4.1.1.3 Dry matter accumulation by weeds

Data on dry matter accumulation (g/m^2) by weeds recorded 30 and 60 DAT and at harvest as affected by different treatments are presented in Tables 6.

All the weed control treatments caused significant reduction in dry matter accumulation by weeds in both the years. Hand weeding was the most effective treatment in lowering the dry matter accumulation by weeds at each growth stages in both the years. This treatment proved significantly superior to the rest of the treatments in arresting the dry matter accumulation by weeds. Flufenacet was the next best treatment and caused significant reduction in dry weight of weeds compared to anilofos at 30 and 60 day stages and pretilachlor at all stages in both the years. However, in both the years at harvest stage, flufenacet and anilofos treatments effected similar decrease. Pretilachlor was the least effective herbicide, it proved significantly inferior to anilofos and hand weeding.

4.1.1.4 Weed index

Data on weed index (%) as influenced by different treatments are presented in Table 7 and graphically depicted in Figure 4.

Table 6. Effect of treatments on dry matter accumulation (g/m²) by weeds in rice at different growth stages

treatment	30 DAT		60 DAT		At harvest	
	2000	2001	2000	2001	2000	2001
	nilofos 500 g/ha	4.39 (18.80)	5.05 (25.04)	8.14 (65.76)	10.51 (110.00)	2.54 (5.96)
retilachlor 750 g/ha	5.87 (33.96)	6.19 (37.84)	12.00 (123.68)	13.29 (176.20)	2.79 (7.33)	3.54 (12.03)
lufenacet 120 g/ha	4.05 (15.88)	4.59 (20.60)	7.46 (55.40)	9.44 (88.84)	2.37 (5.10)	2.97 (8.33)
and weeding	3.01 (8.60)	3.43 (11.32)	6.37 (40.08)	8.01 (63.72)	2.12 (4.04)	2.76 (7.15)
weedy check	11.34 (128.24)	10.94 (119.44)	22.30 (497.84)	23.35 (544.84)	5.61 (31.08)	6.46 (41.22)
Em +	0.05	0.07	0.09	0.10	0.06	0.05
D (P=0.05)	0.14	0.20	0.25	0.28	0.17	0.14

figures in parentheses indicate original values

Table 7. Weed index (%) of different weed control treatments

Treatment	2000	2001
Anilofos 500 g/ha	60.63	57.05
Pretilachlor 750 g/ha	54.21	50.94
Flufenacet 120 g/ha	61.33	58.56
Hand weeding	63.45	61.69
Weedy check	-	-

Table 8. Weed control efficiency (%) of different weed control treatments

Treatment	2000			2001		
	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest
Anilofos 500 g/ha	85.33	86.79	80.82	79.03	79.81	78.16
Pretilachlor 750 g/ha	73.51	75.14	76.41	68.31	67.66	70.81
Flufenacet 120 g/ha	87.61	88.87	83.62	82.75	83.69	79.79
Hand weeding	93.29	91.95	87.00	90.52	88.30	82.65
Weedy check	-	-	-	-	-	-

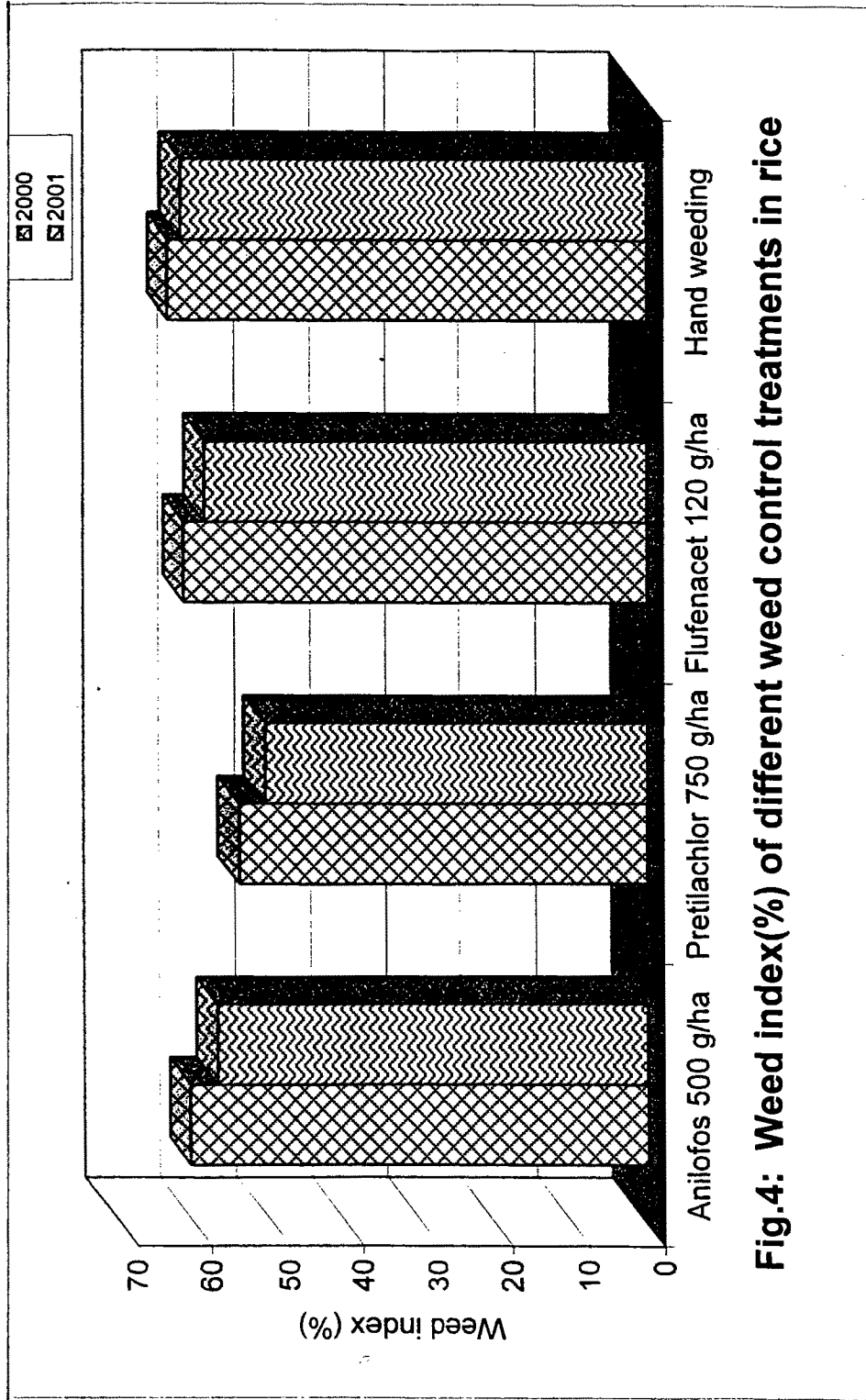


Fig.4: Weed index(%) of different weed control treatments in rice

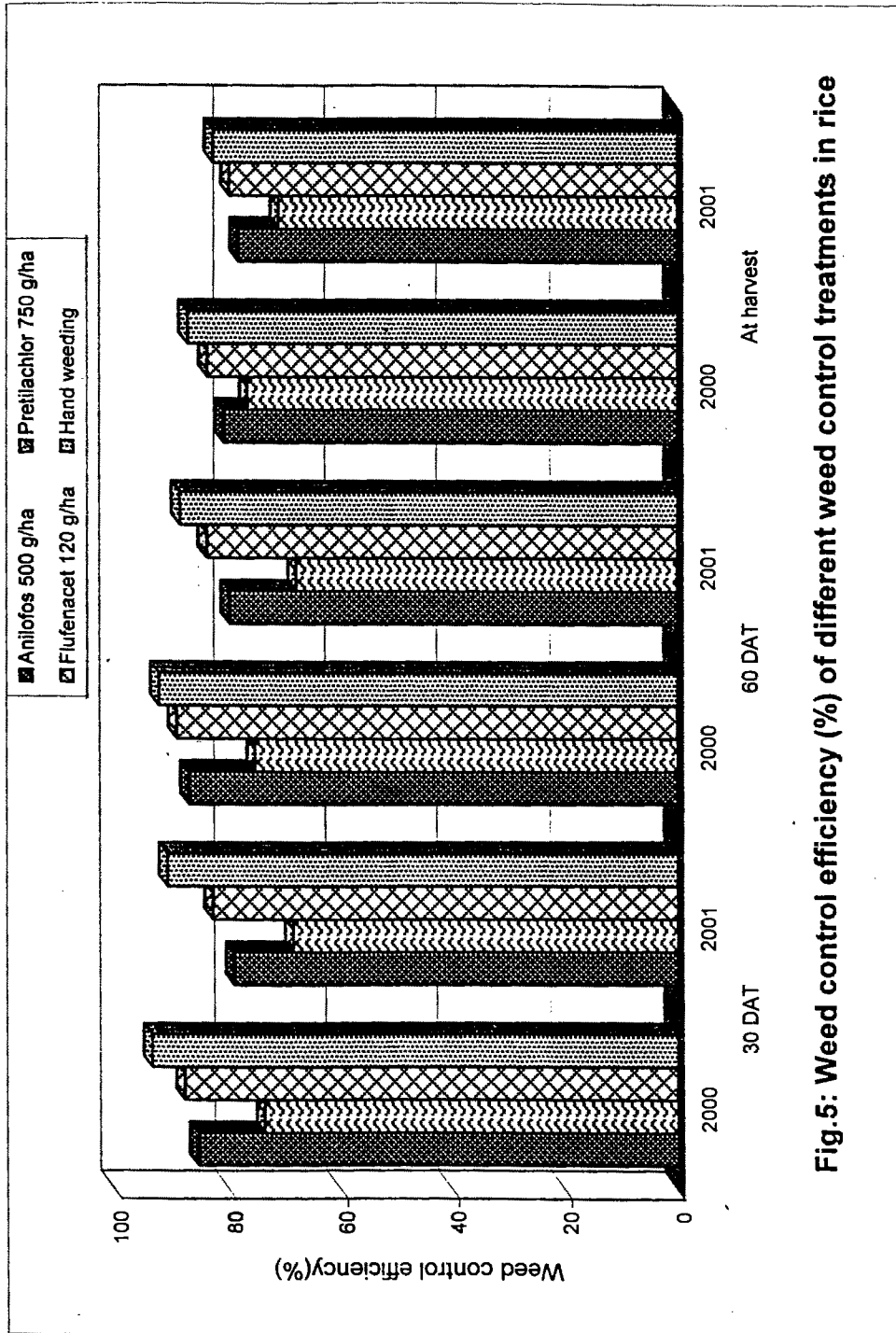


Fig.5: Weed control efficiency (%) of different weed control treatments in rice

In both the years, two hand weedings registered the highest weed index (61.7-63.4%) closely followed by flufenacet (58.5-61.3%) and anilofos (57.0-60.6%). The lowest weed index (50.9-54.2%) was of pretilachlor.

4.1.1.5 Weed control efficiency

Data pertaining to weed control efficiency (%) as influenced by different treatments are presented in Table 8 and depicted in Figure 5.

In both the years, the highest weed control efficiency (82.6-93.2%) was of hand weeding followed by flufenacet (79.7-88.8%) and anilofos (78.1-86.8%). The lowest weed control efficiency was of pretilachlor (67.6-76.4%).

4.1.2 Observations on rice

4.1.2.1 Plant height

Data pertaining to plant height (cm) recorded 30 and 60 DAT and at harvest of the crop are presented in Table 9.

In all the weed control treatments significantly higher plant height was recorded compared to weedy check at all growth stages in both the years. At 30 days stage in 2000, in anilofos, pretilachlor and hand weeding plants were similar in height but significantly taller than the plants in other treatments. However, in 2001, hand weeding being at par with anilofos effected significantly higher increase in plant height compared to rest of the treatments. Minimum height of plants was recorded in flufenacet at this stage in both the years.

At 60 days and at harvest stages in both the years, plants were significantly taller in hand weeding compared to other treatments. Plants did not differ significantly in height in anilofos and flufenacet treated plots except at 60 days stage in 2001 when in latter significantly higher plant height was recorded.

Among the weed control treatments, plant height was lower in pretilachlor which, however, was at par with that under flufenacet in 2000 and anilofos at 60 days stage in 2001.

4.1.2.2 Dry matter accumulation by rice

Data on dry matter accumulation (g/hill) by rice 30 and 60 DAT and at harvest as influenced by different treatments are presented in Table 10.

All the weed control treatments effected marked improvement in dry matter accumulation by rice compared to weedy check. In both the years, 30 DAT, significantly higher dry matter accumulation by rice was recorded in the plots treated with anilofos compared to other treatments. Pretilachlor was the next best treatment in which significantly higher dry matter accumulation was recorded compared to rest of the treatments except flufenacet in 2001. The lowest dry matter accumulation among the weed control treatment was in hand weeding.

In both the years, at 60 days and at harvest stages in two hand weedings dry matter accumulation by rice was significantly higher compared to other treatments. At 60 days stage in 2000, anilofos proved significantly superior to flufenacet but no significant difference existed between them at any other stages in both the years. Dry matter accumulation was lowest in pretilachlor among the weed control treatments.

4.1.2.3 Number of tillers

Data pertaining to number of tillers per rice hill at different growth stages are given in Table 11.

Table 9. Effect of treatments on plant height (cm) of rice at different growth stages

Treatment	2000			2001		
	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest
Anilofos 500 g/ha	66.04	91.34	105.30	63.94	88.34	101.75
Pretilachlor 750 g/ha	65.07	88.30	101.82	63.31	86.61	98.81
Flufenacet 120 g/ha	62.90	90.75	104.11	62.45	90.66	103.80
Hand weeding	65.15	95.72	111.01	65.20	96.46	111.67
Weedy check	57.05	82.07	93.78	59.43	82.72	94.50
S.Em ± CD (P=0.05)	0.63 1.80	0.85 2.40	0.87 2.46	0.57 1.62	0.75 2.13	0.90 2.56

Table 10. Effect of treatments on dry matter accumulation (g/hill) by rice at different growth stages

Treatment	2000			2001		
	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest
Anilofos 500 g/ha	4.40	26.50	40.08	4.37	23.03	37.52
Pretilachlor 750 g/ha	4.21	23.63	37.13	4.12	21.59	35.33
Flufenacet 120 g/ha	4.03	25.02	39.83	4.05	23.24	38.47
Hand weeding	3.96	28.36	42.20	3.75	26.69	42.85
Weedy check	2.17	14.53	23.01	2.00	14.48	22.57
S.Em ± CD (P=0.05)	0.05 0.14	0.30 0.85	0.47 1.34	0.07 0.20	0.26 0.74	0.70 1.99

All the weed control treatments brought about significant increase in tiller number compared to weedy check. At 30 days stage in both the years, maximum number of tillers were recorded in flufenacet. It was at par with anilofos but proved significantly superior to rest of the treatments. Among the weed control treatments significantly lower number of tillers were recorded in pretilachlor at all the stages in both the years.

In both the years, 60 DAT and at harvest, two hand weedings effected maximum increase in tiller number but was at par with flufenacet and anilofos except 60 DAT in 2001.

4.1.2.4 Number of panicles per rice hill and panicle length

Data on number of panicles per rice hill and panicle length (cm) as affected by different treatments are presented in Table 12.

Weed control treatments caused measurable improvement in number of panicles and panicle length compared to weedy check. Hand weeding resulted in the maximum panicle number and panicle length and proved significantly superior to other treatments. Flufenacet and anilofos treatments recorded almost similar number of panicles and panicle length and were significantly superior to pretilachlor in both years.

4.1.2.5 Grain weight per panicle and 1000-grain weight

Data on grain weight per panicle (g) and 1000-grain weight (g) of rice as influenced by different treatments are presented in Table 13.

Table 11. Effect of treatments on number of tillers per rice hill at different growth stages

Treatment	2000			2001		
	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest
Anilofos 500 g/ha	15.6	16.3	16.0	14.2	14.5	14.3
Pretilachlor 750 g/ha	13.3	14.1	14.1	13.1	13.5	13.1
Flufenacet 120 g/ha	15.7	16.2	15.7	14.6	15.0	14.7
Hand weeding	14.8	16.6	16.3	13.6	15.3	15.0
Weedy check	9.9	10.0	9.7	8.8	9.2	8.3
S.Em ± CD (P=0.05)	0.20 0.57	0.21 0.59	0.22 0.62	0.26 0.74	0.25 0.71	0.25 0.71

Table 12. Effect of treatments on number of panicles per hill and panicle length (cm) of rice

Treatment	2000		2001	
	Panicles/ hill	Panicle length	Panicles/ hill	Panicle length
Anilofos 500 g/ha	9.2	25.5	9.1	25.0
Pretilachlor 750 g/ha	8.6	24.2	8.3	24.1
Flufenacet 120 g/ha	9.5	25.2	9.2	25.3
Hand weeding	10.0	26.8	9.9	26.4
Weedy check	6.1	22.5	6.2	22.6
S.Em ± CD (P=0.05)	0.14 0.39	0.31 0.88	0.20 0.56	0.30 0.85

Table 13. Effect of treatments on grain weight per panicle (g) and 1000-grain weight (g) of rice

Treatment	2000		2001	
	Grain weight/ panicle	1000-grain weight	Grain weight/ panicle	1000-grain weight
Anilofos 500 g/ha	2.04	21.09	1.99	20.85
Pretilachlor 750 g/ha	1.89	20.79	1.80	20.44
Flufenacet 120 g/ha	2.15	21.50	2.02	20.95
Hand weeding	2.29	21.84	2.20	21.17
Weedy check	1.41	19.46	1.50	19.05
S.Em +	0.04	0.21	0.05	0.23
CD (P=0.05)	0.11	0.59	0.14	0.65

Weed control treatments brought about significant increase in the grain weight/panicle and 1000-grain weight. In both the years, significantly higher grain weight/panicle was recorded in hand weeding compared to other treatments. Flufenacet caused significantly higher increase in grain weight/panicle compared to pretilachlor in both years and anilofos in 2000.

In both the years, two hand weedings and flufenacet caused identical increase in 1000-grain weight. Former treatment proved statistically superior to all other treatments except anilofos in 2001. While flufenacet was at par with anilofos but registered significantly higher 1000-grain weight compared to pretilachlor in 2000. However, no significant differences existed among the three herbicide treatments in 2001.

4.1.2.6 Crop yield

Data pertaining to grain and straw yield (kg/ha) and harvest index (%) as influenced by different treatments are presented in Table 14. Grain and straw yield are also depicted graphically in Figures 6 and 7, respectively.

4.1.2.6.1. Grain yield: In both the years weed control treatments brought about significant increase in grain yield compared to weedy check. Hand weeding resulted in the highest increase which proved significantly superior to all other treatments. Grain yield was marginally higher in the flufenacet treated plots compared to anilofos but both recorded significantly higher grain yield over pretilachlor. In both the years, increase in grain yield was lowest in the plots treated with pretilachlor among the weed control treatments.

4.1.2.6.1. Straw yield: Weed control treatments had marked effect on the straw yield of rice in both the years. Two hand weedings recorded significantly higher straw yield compared to rest of the treatments. No significant difference existed among anilofos and flufenacet. Pretilachlor was least effective and recorded significantly lower straw yield among the weed control treatments.

4.1.2.6.2. Harvest index: Weed control treatments resulted in significant increase in harvest index compared to weedy check in both the years. Harvest index was highest in flufenacet but it was statistically at par with anilofos. Both these treatments recorded significantly higher value of harvest index compared to other treatments in both the years. Among the weed control treatments, significantly lower harvest index was recorded in pretilachlor in 2000 but it was statistically at par with hand weeding in the year 2001.

4.1.3 Herbicide residues

The residue levels of anilofos, pretilachlor and flufenacet ($\mu\text{g/g}$) in soil initially and at harvest and in rice grain are given in Table 15.

Table 14. Effect of treatments on grain yield (kg/ha), straw yield (kg/ha) and harvest index (%) of rice

Treatment	Grain yield		Straw yield		Harvest index			
	2000	2001	Pooled	2000	2001	Pooled	2000	2001
nilofos 500 g/ha	6229	5837	6033.0	9636	9375	9505.5	39.26	38.37
retilachlor 750 g/ha	5355	5111	5233.0	9060	8919	8989.5	37.14	36.43
lufenacet 120 g/ha	6341	6050	6195.5	9595	9529	9562.0	39.79	38.83
land weeding	6709	6545	6627.0	10789	11299	11044.0	38.34	36.68
weedy check	2452	2507	2479.5	4517	4623	4570.0	35.18	35.16
LSD (P=0.05)	97	84		107	116		0.19	0.20
SEM	276	238		304	330		0.54	0.56

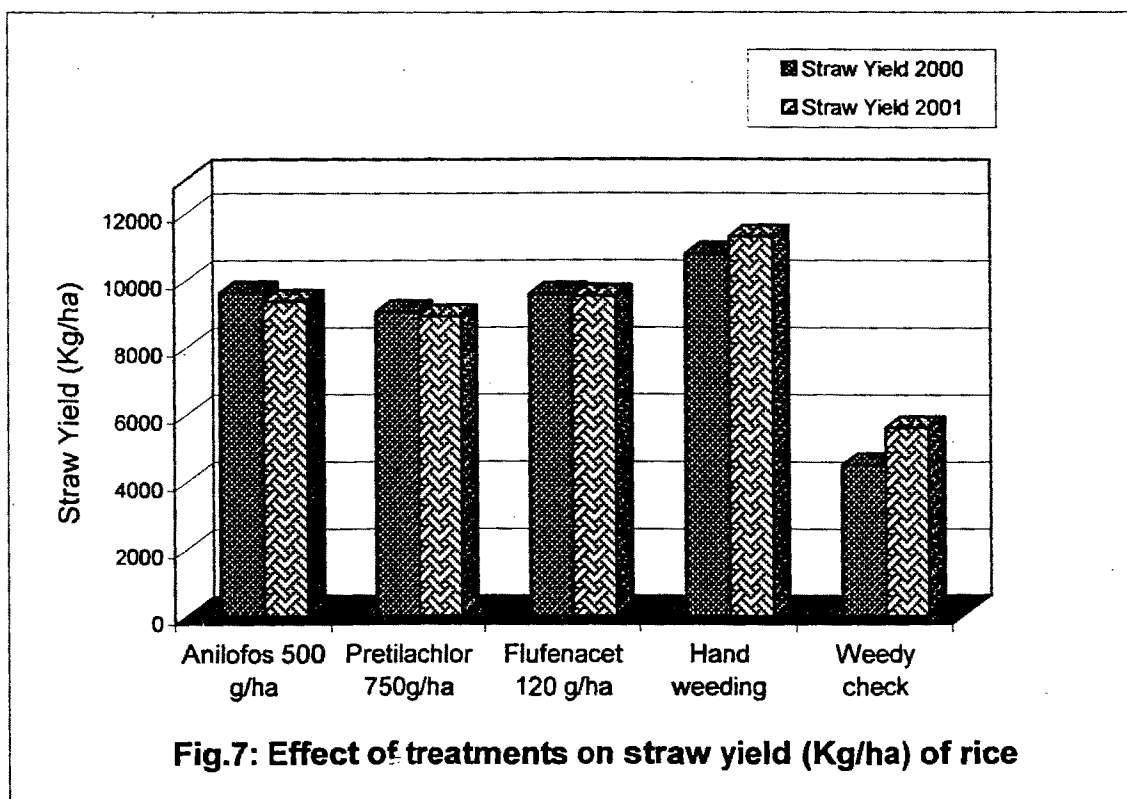
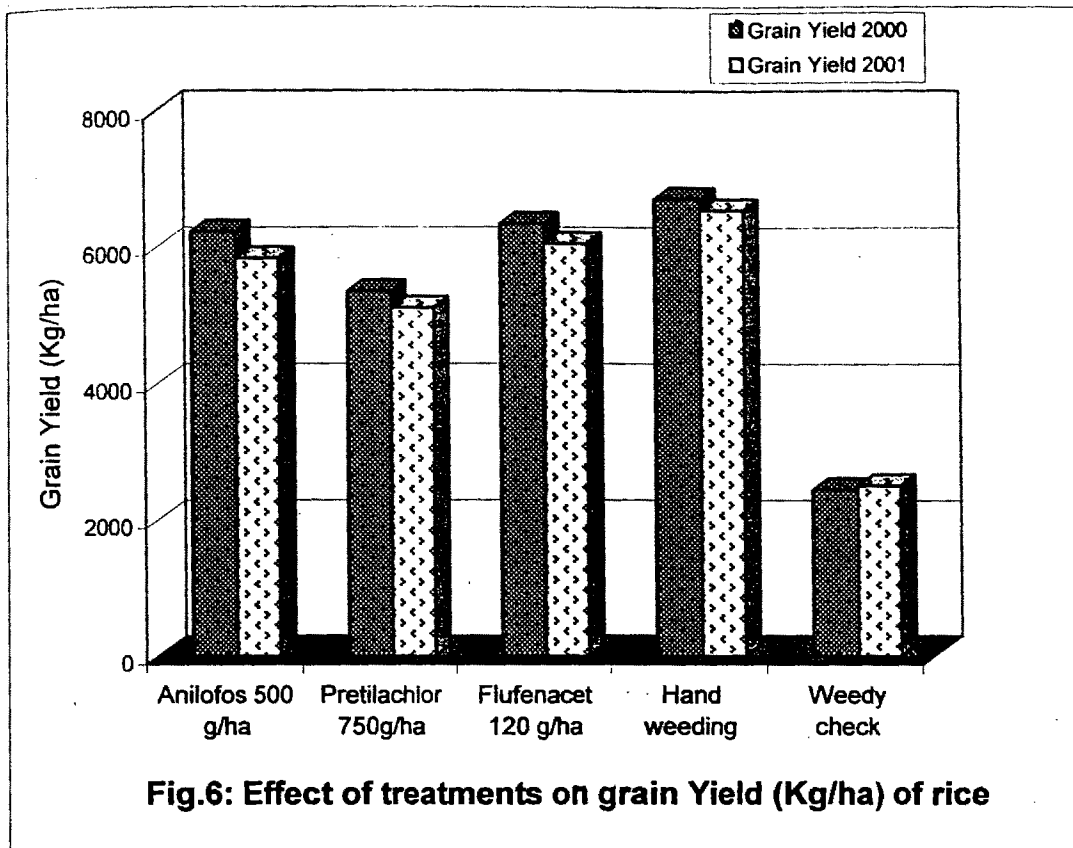


Table 15. Herbicide residues ($\mu\text{g/g}$) in soil initially and at crop harvest and in rice grain

Treatment	2000			2001		
	Soil		Grain	Soil		Grain
	0 day	At harvest		0 day	At harvest	
Anilofos 500 g/ha	0.691	ND	ND	0.703	ND	ND
Pretilachlor 750 g/ha	0.928	ND	ND	0.932	ND	ND
Flufenacet 120 kg/ha	0.114	ND	ND	0.106	ND	ND

ND: Not detectable

4.1.3.1 Soil

The initial deposits of anilofos at 500 g/ha, pretilachlor at 750 g/ha and flufenacet at 120 g/ha were found to be 0.691, 0.928 and 0.114 $\mu\text{g/g}$ respectively in 2000 and 0.703, 0.932 and 0.106 $\mu\text{g/g}$, respectively in 2001. All the herbicides were below detectable limits at crop harvest in both the years.

4.1.3.2 Grain

In both the years, residues of anilofos, pretilachlor and flufenacet were below detectable limits in grain.

4.2 Wheat

4.2.1 Observations on weeds

4.2.1.1 Weed flora

In both the years (2000-01 and 2001-02), grass (72.5%) and broadleaf (27.5%) weeds occurred in wheat field. Among grass weeds, the dominant species were *Phalaris minor* (27.1%), *Avena ludoviciana* (16.8%), *Poa annua* (6.9%) and *Imperata cylindrica* (3.9%). The predominant broadleaf weeds were

Coronopus didymus (11.3%), *Melilotus indica* (6.8%) and *Rumex* sp. (5.2%). Besides, other weed species which infested in the field were *Chenopodium murale*, *Anagallis arvensis*, *Fumeria parviflora*, *Convolvulus arvensis*, *Cynodon dactylon* and *Cyperus rotundus*.

4.2.1.2 Weed population

Data on population of grass, broadleaf and total weeds (no. of plants/m²) recorded 60 and 90 DAS and at harvest as influenced by different treatments are presented in Tables 16, 17 and 18.

4.2.1.2.1 Grass weeds: Treatments applied to rice had no significant effect on number of grass weeds at any stage in any year (2000-01 and 2001-02). Direct effect of treatments was evident in both the years. Weed control treatments brought about marked reduction in population compared to weedy check. In both the years, 60 and 90 DAS, metribuzin was most effective in lowering the population. It was significantly superior to all other treatments. The next most effective treatment was sulfosulfuron which recorded significantly lower population compared to hand weeding. In both the years at harvest, metribuzin registered lowest population and was at par with sulfosulfuron while in the year 2001-02 it was proved superior to hand weeding (Table 18). Sulfosulfuron and hand weeding caused identical decrease in both years.

4.2.1.2.2 Broadleaf weeds: Population of broadleaf weeds was not affected due to residual effect of herbicides except at 60 days stage in 2000-01. At this stage, significantly lower population was recorded in hand weeding compared to weedy check (Table 16).

Table 16. Residual and direct effect of treatments on weed population per m² in wheat (60 DAS)

Treatment	Grass weeds		Broadleaf weeds		Total weeds	
	2000-01	2001-02	2000-01	2001-02	2000-01	2001-02
Residual effect						
Anilofos 500 g/ha	11.2 (204.0)	11.6 (198.8)	8.3 (100.4)	7.7 (84.4)	14.2 (304.4)	14.1 (283.2)
Pretilachlor 750 g/ha	11.0 (202.0)	11.5 (197.6)	8.3 (101.6)	7.9 (84.8)	14.0 (303.6)	14.1 (282.2)
Flufenacet 120 g/ha	10.9 (192.4)	11.6 (202.4)	8.5 (102.0)	8.0 (89.6)	14.1 (294.4)	14.2 (292.0)
Hand weeding	10.9 (196.8)	11.6 (198.4)	8.0 (96.8)	7.8 (84.4)	13.7 (293.6)	14.1 (282.8)
Weedy check	11.3 (203.2)	11.7 (200.4)	8.7 (103.2)	8.0 (87.6)	14.4 (306.4)	14.3 (288.0)
SEm ± CD (P=0.05)	0.30 NS	0.21 NS	0.21 0.60	0.19 NS	0.34 NS	0.20 NS
Direct effect						
Sulfosulfuron 25 g/ha	6.4 (39.2)	7.3 (52.8)	9.7 (92.8)	8.9 (78.4)	11.6 (132.0)	11.5 (131.2)
Metribuzin 200 g/ha	3.9 (16.4)	4.4 (21.2)	1.5 (2.0)	1.6 (2.8)	4.3 (18.4)	4.7 (24.0)
Hand weeding	7.9 (64.0)	9.2 (82.4)	6.0 (36.0)	6.0 (34.4)	9.9 (100.0)	11.0 (116.8)
Weedy check	25.9 (678.4)	25.3 (641.6)	16.3 (272.0)	15.0 (228.0)	30.6 (950.4)	29.4 (869.6)
SEm ± CD (P=0.05)	0.32 0.92	0.23 0.66	0.23 0.66	0.21 0.60	0.37 1.06	0.22 0.63

Figures in parentheses indicate original values

Table 17. Residual and direct effect of treatments on weed population per m² in wheat (90 DAS)

Treatment	Grass weeds		Broadleaf weeds		Total weeds	
	2000-01	2001-02	2000-01	2001-02	2000-01	2001-02
Residual effect						
Anilofos 500 g/ha	11.0 (187.6)	11.2 (186.4)	8.2 (93.6)	7.6 (80.0)	13.9 (281.2)	13.7 (266.4)
Pretilachlor 750 g/ha	10.8 (187.6)	11.1 (186.8)	8.4 (96.0)	7.6 (80.0)	13.9 (283.6)	13.6 (266.8)
Flufenacet 120 g/ha	11.0 (182.4)	11.0 (187.6)	8.3 (94.4)	7.7 (82.8)	14.0 (276.8)	13.6 (270.4)
Hand weeding	10.8 (184.4)	11.3 (187.2)	8.0 (92.0)	7.4 (78.8)	13.6 (276.4)	13.7 (266.0)
Weedy check	11.2 (190.0)	11.3 (187.2)	8.0 (94.4)	7.7 (82.0)	14.1 (284.4)	13.9 (269.2)
SEm ± CD (P=0.05)	0.27 NS	0.17 NS	0.18 NS	0.17 NS	0.29 NS	0.19 NS
Direct effect						
Sulfosulfuron 25 g/ha	6.9 (46.8)	7.0 (49.2)	9.5 (88.4)	8.7 (76.0)	11.7 (135.2)	11.2 (125.2)
Metribuzin 200 g/ha	4.1 (17.6)	4.0 (18.0)	1.5 (2.4)	1.4 (2.0)	4.4 (20.0)	4.3 (20.0)
Hand weeding	8.3 (68.0)	9.2 (80.8)	6.3 (39.6)	5.9 (34.0)	10.4 (107.6)	10.9 (114.8)
Weedy check	24.5 (612.8)	24.5 (600.0)	15.6 (245.6)	14.5 (211.2)	29.1 (858.4)	28.4 (811.2)
SEm ± CD (P=0.05)	0.29 0.83	0.19 0.54	0.20 0.57	0.19 0.54	0.32 0.92	0.21 0.60

Figures in parentheses indicate original values

Table 18. Residual and direct effect of treatments on weed population per m² in wheat (at harvest)

Treatment	Grass weeds		Broadleaf weeds		Total weeds	
	2000-01	2001-02	2000-01	2001-02	2000-01	2001-02
Residual effect						
Anilofos 500 g/ha	4.6 (24.4)	6.1 (40.4)	5.8 (47.6)	5.9 (48.8)	7.6 (72.0)	8.7 (89.2)
Pretilachlor 750 g/ha	4.6 (25.2)	6.2 (41.6)	5.5 (44.8)	6.2 (51.6)	7.3 (70.0)	9.0 (93.2)
Flufenacet 120 g/ha	4.4 (21.6)	6.2 (42.4)	5.6 (45.2)	5.9 (51.2)	7.3 (66.8)	8.8 (93.6)
Hand weeding	4.4 (21.6)	5.8 (38.4)	5.5 (44.0)	5.9 (50.0)	7.3 (65.6)	8.4 (88.4)
Weedy check	4.6 (24.4)	6.2 (41.2)	5.9 (48.0)	6.3 (51.6)	7.7 (72.4)	9.0 (92.8)
SEm + CD (P=0.05)	0.25 NS	0.23 NS	0.14 NS	0.15 NS	0.24 NS	0.24 NS
Direct effect						
Sulfosulfuron 25 g/ha	3.7 (13.6)	5.0 (24.4)	5.8 (33.6)	5.8 (34.8)	6.9 (47.2)	7.7 (59.2)
Metribuzin 200 g/ha	3.2 (10.4)	4.6 (22.0)	1.0 (0.8)	1.4 (2.4)	3.3 (11.2)	4.8 (24.4)
Hand weeding	4.0 (16.0)	5.7 (32.8)	4.5 (20.4)	4.9 (23.2)	6.0 (36.4)	7.5 (56.0)
Weedy check	7.2 (53.6)	9.1 (84.0)	11.4 (128.8)	11.9 (142.0)	13.4 (182.4)	15.0 (226.0)
SEm + CD (P=0.05)	0.28 0.80	0.25 0.72	0.15 0.43	0.17 0.49	0.26 0.74	0.26 0.74

Figures in parentheses indicate original values

Weed control treatments in wheat caused significant reduction in population compared to weedy check at all the stages. In both years, metribuzin effected maximum reduction at all the stages and proved significantly superior to other treatments. Hand weeding in wheat was the next best treatment which recorded significantly lower population compared to sulfosulfuron at all the stages. Sulfosulfuron was the least effective treatment, among weed control treatments, in checking the population of broadleaf weeds in wheat.

4.2.1.2.3 Total weeds: In both years, effect of rice applied treatments was identical on total population of weeds.

Significantly lower population was recorded in the weed control treatments applied to wheat compared to weedy check. Metribuzin registered lowest population and proved significantly superior to all other treatments in arresting weed population in both the years. At all the stages, hand weeding was the next most effective treatment. It proved significantly superior to sulfosulfuron in 2000-01 but was at par in 2001-02.

4.2.1.3 Dry matter accumulation by weeds

Data on dry matter accumulation (g/m^2) by weeds recorded at different stages are presented in Table 19.

Rice applied treatments did not cause any appreciable variation in dry matter accumulation in any year of experimentation.

Weed control treatments applied to wheat (direct effect) brought about significant reduction in the dry matter accumulation by weeds compared to weedy check. At all the stages, metribuzin was the most effective treatment in reducing dry matter accumulation in both the years and proved significantly

Table 19. Residual and direct effect of treatments on dry matter accumulation (g/m²) by weeds in wheat at different growth stages

Treatment	60 DAS		90 DAS		At harvest	
	2000-01	2001-02	2000-01	2001-02	2000-01	2001-02
Residual effect						
Anilofos 500 g/ha	5.17 (32.56)	4.74 (27.76)	6.54 (56.04)	6.00 (47.04)	4.85 (27.40)	4.99 (28.92)
Pretilachlor 750 g/ha	5.30 (33.72)	4.67 (27.40)	6.53 (56.48)	6.06 (47.48)	4.69 (26.56)	5.17 (30.68)
Flufenacet 120 g/ha	5.26 (34.12)	4.59 (26.44)	6.41 (54.68)	6.05 (48.00)	4.71 (26.32)	5.11 (30.64)
Hand weeding	5.19 (32.84)	4.51 (26.40)	6.35 (54.60)	6.02 (46.76)	4.86 (26.80)	4.94 (29.52)
Weedy check	5.28 (33.56)	4.80 (28.08)	6.65 (56.80)	6.10 (48.20)	4.97 (28.00)	5.14 (30.16)
SEm ± CD (P=0.05)	0.07 NS	0.13 NS	0.14 NS	0.08 NS	0.13 NS	0.10 NS
Direct effect						
Sulfosulfuron 25 g/ha	4.75 (21.68)	4.12 (16.20)	5.47 (28.88)	5.05 (25.44)	4.72 (21.12)	4.85 (22.44)
Metribuzin 200 g/ha	2.72 (7.16)	2.29 (5.16)	2.75 (7.64)	2.71 (7.28)	2.47 (6.28)	2.52 (6.36)
Hand weeding	4.09 (16.16)	3.63 (12.76)	5.15 (26.00)	4.74 (21.00)	4.07 (16.20)	4.45 (19.36)
Weedy check	9.39 (88.48)	8.59 (74.72)	12.60 (160.40)	11.68 (136.24)	8.00 (64.44)	8.46 (71.80)
SEm ± CD (P=0.05)	0.08 0.23	0.15 0.43	0.15 0.43	0.09 0.26	0.14 0.40	0.11 0.31

Figures in parentheses indicate original values

superior to other treatments. Hand weeding was the next best treatment which proved significantly superior to sulfosulfuron except at 90 days stage in 2000-01. Among the weed control treatments, sulfosulfuron was the least effective treatment in checking dry matter production by weeds.

4.2.1.4 Weed index

Data on weed index (%) as influenced by different wheat applied treatments are given in Table 20 and depicted in Fig. 8. In both the years, weed index of hand weeding was highest (23.7 to 27.0%) followed by sulfosulfuron (19.3 to 21.2%) and metribuzin (12.0-12.8%).

4.2.1.5 Weed control efficiency

Data on weed control efficiency (%) at different stages as influenced by weed control treatments applied in wheat are presented in Table 21 and depicted in Fig. 9.

The highest weed control efficiency (90.25 to 95.23%) was of metribuzin in both the years. Hand weeding was the next best treatment with weed control efficiency of 73.03 to 84.58%. Weed control efficiency was lowest of sulfosulfuron (67.22 to 81.99%)

4.2.2 Observations on wheat

4.2.2.1 Plant population

Data pertaining to plant population (no. of plants/metre row-length) recorded 20 DAS are presented in Table 22.

In both the years, plant population was not affected significantly by direct and residual effect of treatments.

Table 20. Weed index (%) of different weed control treatments

Treatment	2000-01	2001-02
Sulfosulfuron 25 g/ha	21.20	19.30
Metribuzin 200 g/ha	12.80	12.07
Hand weeding	27.10	23.74
Weedy check	-	-

Table 21. Weed control efficiency (%) of different weed control treatments

Treatment	2000-01			2001-02		
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
Sulfosulfuron 25 g/ha	75.49	81.99	67.22	78.31	81.32	68.74
Metribuzin 200 g/ha	91.90	95.23	90.25	93.09	94.65	91.14
Hand weeding	81.73	83.79	74.86	82.92	84.58	73.03
Weedy check	-	-	-	-	-	-

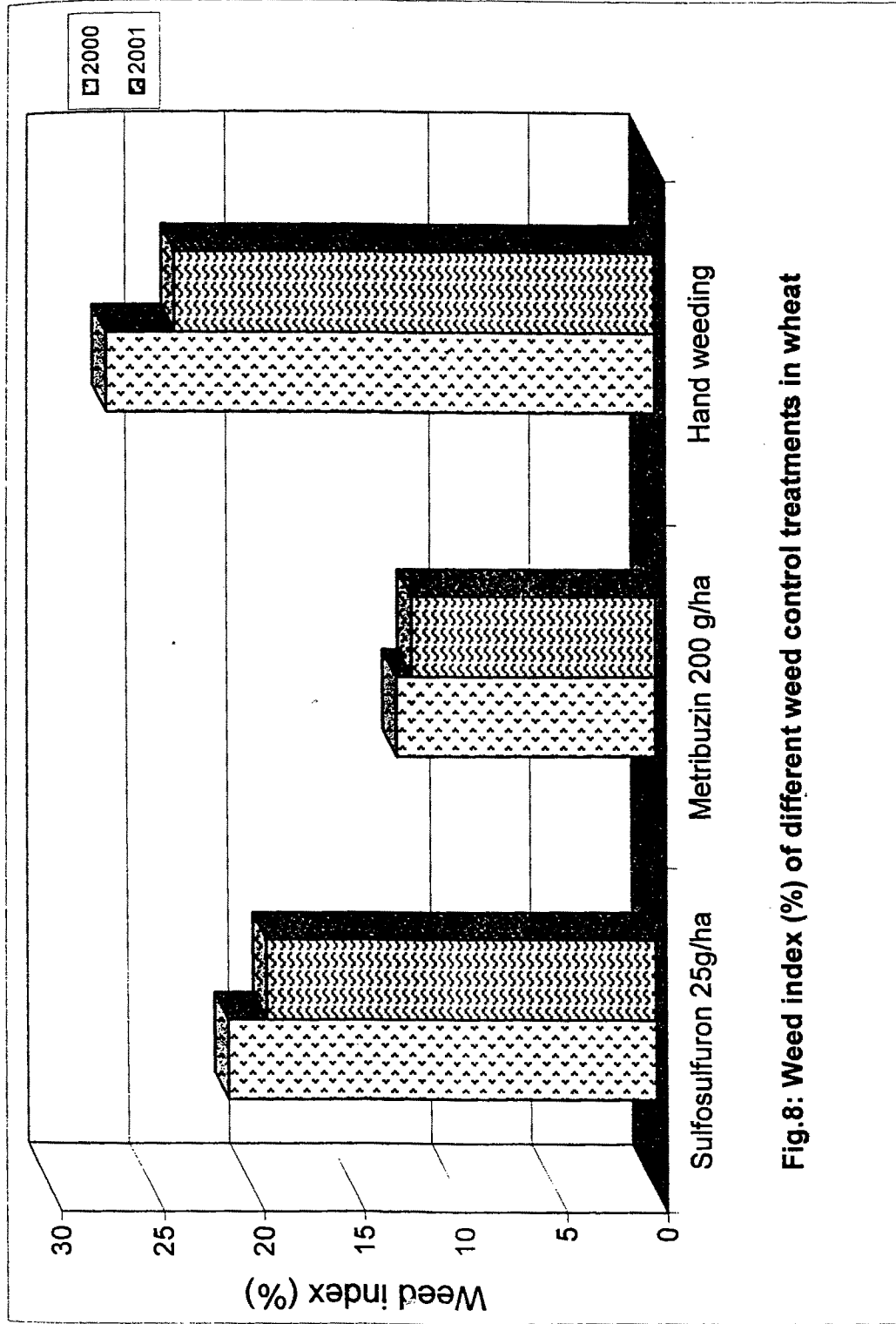


Fig.8: Weed index (%) of different weed control treatments in wheat

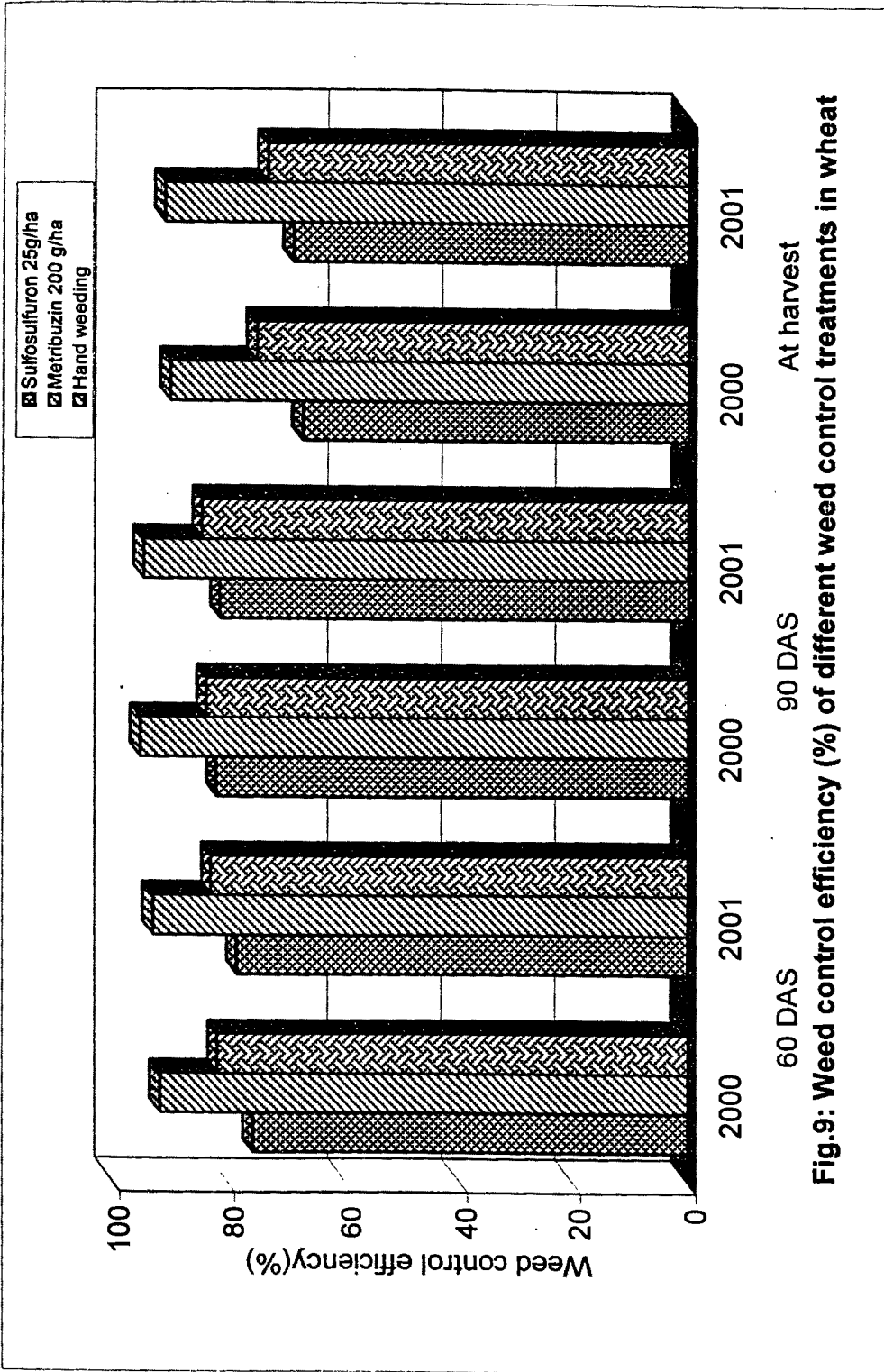


Fig.9: Weed control efficiency (%) of different weed control treatments in wheat

Table 22. Residual and direct effect of treatments on population (no./mrl*) of wheat

Treatment	2000-01	2001-02
Residual effect		
Anilofos 500 g/ha	36.7	37.7
Pretilachlor 750 g/ha	36.4	37.0
Flufenacet 120 g/ha	37.2	36.9
Hand weeding	37.1	37.4
Weedy check	36.6	37.0
SEm ± CD (P=0.05)	0.89 NS	0.98 NS
Direct effect		
Sulfosulfuron 25 g/ha	36.5	37.2
Metribuzin 200 g/ha	37.0	37.4
Hand weeding	37.2	37.1
Weedy check	36.6	37.1
SEm ± CD (P=0.05)	0.85 NS	0.91 NS

mrl* : meter row-length

4.2.2.2 Plant height

Data on plant height (cm) recorded at different growth stages are given in Table 23.

In both the years, no significant differences were observed in plant height due to residual effect of treatments (applied to rice). Direct effect of treatments was evident. In hand weeding the highest increase in plant height was recorded at all the stages in both the years. This treatment was significantly superior to other treatments except sulfosulfuron at 90 days stage in 2000-01 and 90 DAS and at harvest in 2001-02. In both the years, 60 DAS, significant decrease in the plant height was recorded in metribuzin compared to the rest of the treatments except sulfosulfuron in 2001-02. However, 90 DAS and at harvest, plant height in metribuzin and weedy check was similar.

4.2.2.3 Dry matter accumulation

Data on dry matter accumulation (g/0.5 metre row-length) by wheat recorded at different growth stages are presented in Table 24.

Dry matter accumulation by wheat was not affected significantly due to preceding treatments (applied to rice) in both the years.

At 60 days stage in both the years, significantly higher dry matter accumulation was recorded in hand weeding compared to all other treatments. Sulfosulfuron proved significantly superior to weedy check only in 2001-02. In both the years, 60 and 90 DAS, significantly lower dry matter accumulation was recorded in metribuzin compared to other treatments. In both the years, at 90 days stage, both hand weeding and sulfosulfuron caused identical decrease but recorded significantly higher dry matter accumulation over other treatments. At

Table 24. Residual and direct effect of treatments on dry matter accumulation (g/0.5 mrl*) by wheat at different growth stages

Treatment	2000-01			2001-02		
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
Residual effect						
Anilofos 500 g/ha	16.25	95.47	146.15	16.36	97.62	147.17
Pretilachlor 750 g/ha	16.66	96.81	147.89	15.99	97.05	145.76
Flufenacet 120 g/ha	16.38	96.72	147.67	16.15	97.15	146.29
Hand weeding	16.72	96.79	148.37	16.54	97.43	146.88
Weedy check	15.75	96.11	147.57	15.66	96.66	145.50
SEm ± CD (P=0.05)	0.43 NS	1.61 NS	1.85 NS	0.40 NS	1.54 NS	2.11 NS
Direct effect						
Sulfosulfuron 25 g/ha	16.87	101.27	155.77	16.98	100.89	156.41
Metribuzin 200 g/ha	13.72	86.11	142.24	13.83	87.60	141.82
Hand weeding	18.54	104.32	162.34	18.57	105.26	160.02
Weedy check	16.24	93.82	129.97	15.25	95.23	127.23
SEm ± CD (P=0.05)	0.47 1.35	1.77 5.08	2.03 5.83	0.44 1.26	1.69 4.85	2.31 6.63

mrl* : meter row-length

harvest, maximum dry matter accumulation was recorded in hand weeding and it was statistically superior to other treatments except sulfosulfuron in 2001-02. Dry matter accumulation was significantly lower in metribuzin compared to other weed control treatments.

4.2.2.4 Number of tillers

Data pertaining to number of tillers per metre row-length of wheat recorded 60 and 90 DAS are presented in Table 25.

Tiller number was not markedly affected by preceding treatments either in 2000-01 or 2001-02. Significantly higher number of tillers were recorded in hand weeding compared to other treatments in both the years. Sulfosulfuron was the next best treatment and proved significantly superior to metribuzin and weedy check. In both the years, metribuzin application drastically reduced the tiller number and recorded significantly lower number of tillers compared to all other treatments.

4.2.2.5 Number of effective tillers

Data pertaining to number of effective tillers per metre row-length as influenced by different treatments are given in Table 26.

Rice applied treatments had no effect on number of effective tillers in both the years. All weed control treatments applied to wheat recorded significantly higher number of effective tillers compared to weedy check. Hand weeding registered higher number of effective tillers in both the years and proved significantly superior to other treatments except sulfosulfuron in 2001-02. Among the weed control treatments (applied to wheat), metribuzin recorded significantly lower number of effective tillers in both the years.

Table 25. Residual and direct effect of treatments on tiller number (No./mrl*) of wheat at different growth stages

Treatment	2000-01		2001-02	
	60 DAS	90 DAS	60 DAS	90 DAS
Residual effect				
Anilofos 500 g/ha	121.0	121.5	122.9	122.5
Pretilachlor 750 g/ha	121.6	122.8	121.9	121.5
Flufenacet 120 g/ha	120.6	121.4	122.0	121.0
Hand weeding	122.3	123.7	123.1	123.0
Weedy check	120.0	120.2	121.9	121.3
SEm ± CD (P=0.05)	1.86 NS	1.69 NS	2.07 NS	1.95 NS
Direct effect				
Sulfosulfuron 25 g/ha	127.1	128.9	130.5	130.8
Metribuzin 200 g/ha	98.9	100.9	103.4	104.4
Hand weeding	142.1	143.5	139.9	139.4
Weedy check	116.3	114.2	115.9	113.1
SEm ± CD (P=0.05)	2.04 5.85	1.85 5.31	2.26 6.49	2.13 6.11

mrl* : meter row-length

Table 26. Residual and direct effect of treatments on effective tillers (no./mrl*) of wheat

Treatment	2000-01	2001-02
Residual effect		
Anilofos 500 g/ha	93.6	97.5
Pretilachlor 750 g/ha	94.3	97.3
Flufenacet 120 g/ha	93.7	97.2
Hand weeding	94.4	97.7
Weedy check	93.2	96.9
SEm ±	1.45	1.67
CD (P=0.05)	NS	NS
Direct effect		
Sulfosulfuron 25 g/ha	99.5	103.5
Metribuzin 200 g/ha	87.8	94.1
Hand weeding	107.1	108.3
Weedy check	80.8	83.6
SEm ±	1.59	1.83
CD (P=0.05)	4.56	5.25

mrl* : meter row-length

4.2.2.6 Ear length, grain weight per ear and 1000-grain weight

Data on ear length (cm), grain weight per ear (g) and 1000-grain weight (g) as influenced by different treatments are given in Table 27.

Ear length, grain weight per ear and 1000-grain weight were effected due to direct effect of treatments but not of residual effect (rice applied treatments) in both the years.

Weed control treatments applied to wheat resulted in significantly higher values of all the yield attributes compared to weedy check. In both the years, hand weeding recorded significantly higher values for ear length, grain weight per ear and 1000-grain weight compared to other treatments. Metribuzin was statistically at par with sulfosulfuron in respect of ear length but resulted in significantly higher grain weight per ear compared to the latter. In metribuzin and sulfosulfuron 1000-grain weight was almost alike in 2000-01 but in the former significantly higher 1000-grain weight was recorded compared to sulfosulfuron in 2001-2002.

4.2.2.7 Crop yield

Data pertaining to grain and straw yield (kg/ha) and harvest index (%) as influenced by different treatments are presented in Table 28. Grain and straw yields are also depicted graphically in Figures 10 and 11, respectively.

4.2.2.7.1 Grain yield: Direct effect of treatments on grain yield was distinguished but not of residual effect (rice applied treatments) in both the years. All the weed control treatments applied to wheat resulted in significantly higher increase in grain yield compared to weedy check. The yield in hand weeding was significantly higher compared to other treatments except sulfosulfuron in 2001-

Table 27. Residual effect of treatments on ear length (cm), grain weight per ear (g) and 1000-grain weight (g) of wheat

Treatment	2000-01			2001-02		
	Ear length	Grain weight/ear	1000-grain weight	Ear length	Grain weight/ear	1000-grain weight
Residual effect						
Anilofos 500 g/ha	10.32	2.08	40.08	10.26	2.10	40.58
Pretilachlor 750 g/ha	10.24	2.06	40.36	10.14	2.05	40.63
Flufenacet 120 g/ha	10.15	2.02	40.28	10.18	2.08	40.70
Hand weeding	10.08	2.08	40.37	10.13	2.08	40.78
Weedy check	10.29	2.03	40.21	10.17	2.04	40.56
SEm ±	0.10	0.04	0.22	0.13	0.04	0.23
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Direct effect						
Sulfosulfuron 25 g/ha	10.02	2.00	40.02	10.00	2.04	40.37
Metribuzin 200 g/ha	10.21	2.12	40.58	10.24	2.13	41.23
Hand weeding	10.76	2.26	41.56	11.00	2.24	41.74
Weedy check	9.85	1.85	38.89	9.47	1.89	39.27
SEm ±	0.11	0.04	0.24	0.14	0.03	0.23
CD (P=0.05)	0.31	0.11	0.69	0.40	0.08	0.66

Table 28. Residual and direct effect of treatments on grain yield (kg/ha), straw yield (kg/ha) and harvest index (%) of wheat

Treatment	Grain yield			Straw yield			Harvest index	
	2000-01	2001-02	Pooled	2000-01	2001-02	Pooled	2000-01	2001-02
Residual effect								
Anilofos 500 g/ha	4739	4879	4809.0	7602	7439	7520.5	38.40	39.60
Pretilachlor 750 g/ha	4799	4926	4862.5	7631	7548	7589.5	38.60	39.49
Flufenacet 120 g/ha	4770	4863	4816.5	7728	7420	7574.0	38.16	39.59
Hand weeding	4820	4926	4873.0	7725	7496	7610.5	38.42	39.65
Weedy check	4758	4854	4806.0	7582	7444	7513.0	38.55	39.46
SEm ±	90	105		116	105		0.25	0.18
CD (P=0.05)	NS	NS		NS	NS		NS	NS
Direct effect								
Sulfosulfuron 25 g/ha	5010	5202	5117.5	7964	8099	8053.5	38.59	39.09
Metribuzin 200 g/ha	4577	4745	4661.0	6944	6920	6932.0	39.74	40.65
Hand weeding	5475	5471	5473.0	8565	8013	8295.5	38.99	40.53
Weedy check	4034	4147	4081.5	7122	6843	6965.5	36.08	37.67
SEm ±	98	115		131	137		0.28	0.20
CD (P=0.05)	281	330		376	393		0.80	0.57

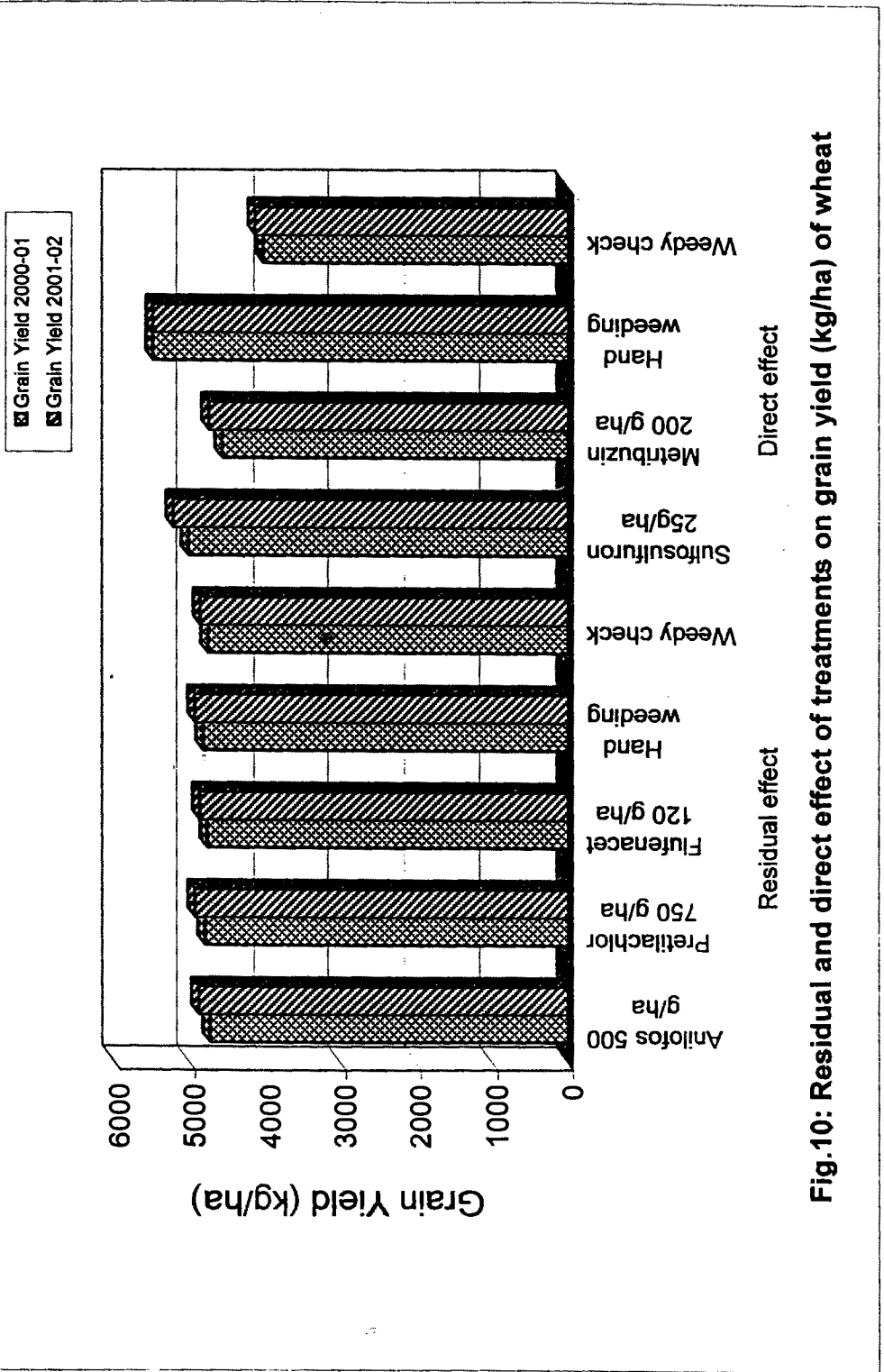


Fig.10: Residual and direct effect of treatments on grain yield (kg/ha) of wheat

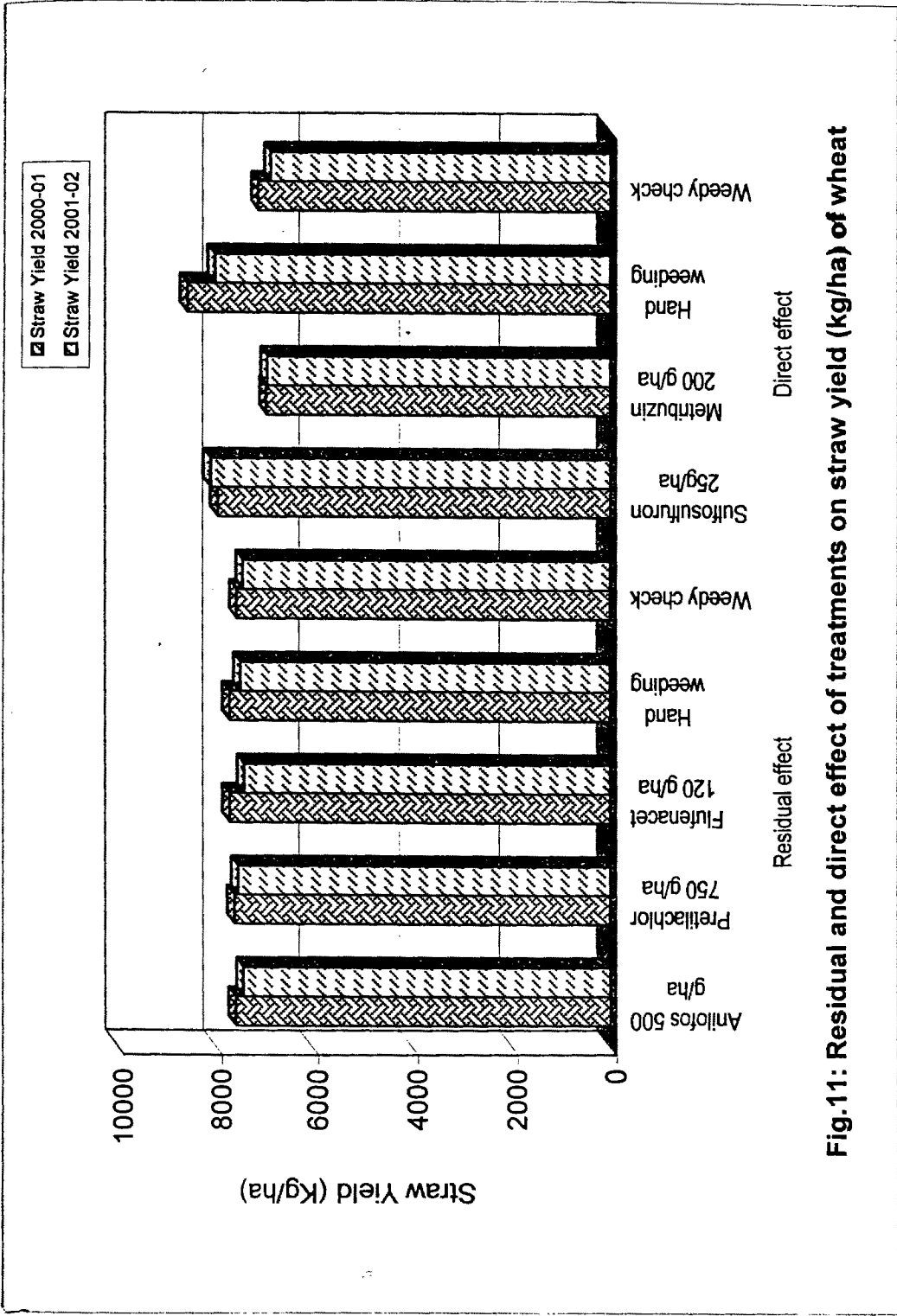


Fig.11: Residual and direct effect of treatments on straw yield (kg/ha) of wheat

02. Among the weed control treatments the lowest yield was recorded in metribuzin in both the years.

4.2.2.7.3 Straw yield: Treatments applied in rice had no marked effect on straw yield either in 2000-01 or 2001-02.

In 2000-01, in hand weeding significantly higher straw yield was recorded compared to other treatments, but in 2001-02, increase in it and sulfosulfuron was similar but significantly higher compared to rest of the treatments. Straw yield was similar in metribuzin and in weedy check in both the years.

4.2.2.7.3 Harvest index: In both the years, harvest index was not affected due to residual effect but was markedly affected due to direct effect. Metribuzin recorded highest value of harvest index in both the years. It was at par with hand weeding but significantly superior to other treatments. The harvest index was significantly higher in hand weeding compared to sulfosulfuron only in 2001-02 and weedy check in both the years.

4.2.3 Herbicide residues

The residue levels of sulfosulfuron and metribuzin ($\mu\text{g/g}$) in soil initially & at harvest and in wheat grain are given in Table 29.

Table 29. Herbicide residues ($\mu\text{g/g}$) in soil initially and at crop harvest and in wheat grain

Treatment	2000-01			2001-02		
	Soil		Grain	Soil		Grain
	0 day	At harvest		0 day	At harvest	
Sulfosulfuron 25 g/ha	0.080	ND	ND	0.088	ND	ND
Metribuzin 200 g/ha	0.211	ND	ND	0.220	ND	ND

ND: Not detectable

4.2.3.1 Soil

The initial deposits of sulfosulfuron and metribuzin were 0.080 and 0.211 $\mu\text{g/g}$, respectively in 2000-01 and 0.088 and 0.220 $\mu\text{g/g}$, respectively in 2001-02. Both the herbicides were below detectable limits at crop harvest in both the years.

4.2.3.2 Grain

No detectable residues of sulfosulfuron and metribuzin were found in grain in both the years.

4.3 Total productivity of cropping system

Data relating to total productivity of cropping system under different treatments are presented in Table 30.

Weed-crop competition reduced the total grain yield by 45.88%. Hand weeding both in rice and wheat recorded highest grain and straw yield compared to other treatment combinations. It resulted in 84.78% and 68.49% increase in grain and straw yield, respectively over weedy check. Hand weeding followed by sulfosulfuron and flufenacet followed by hand weeding were the next best treatment combinations resulting in 78.19 to 78.77% increase in grain yield compared to weedy check.

4.4 Economics of weed control

4.4.1 Rice

Economics of rice cultivation was calculated taking pooled yield (grain and straw) and is presented in Table 31.

Net return was higher in hand weeding followed by flufenacet and anilofos. However, additional return per rupee invested on weed control was

Table 30. Total productivity of cropping system as influenced by different weed control treatments in rice and wheat

treatment	Grain yield (kg/ha)			Straw yield (kg/ha)		
	2000-01	2001-02	Pooled	2000-01	2001-02	Pooled
1W1 Anilofos fb* sulfosulfuron	11449	10975	11212.0	17665	17400	17532.5
1W2 Anilofos fb metribuzin	10704	10535	10619.5	16606	16217	16411.5
1W3 Anilofos fb hand weeding	11602	11314	11458.0	18091	17420	17755.5
1W4 Anilofos fb weedy check	10118	10039	10078.5	16592	16217	16404.5
2W1 Pretilachlor fb sulfosulfuron	10507	10349	10428.0	17247	17112	17179.5
2W2 Pretilachlor fb metribuzin	10040	9887	9963.5	16117	15895	16006.0
2W3 Pretilachlor fb hand weeding	10857	10591	10724.0	17763	16960	17361.5
2W4 Pretilachlor fb weedy check	9210	9320	9265.0	16024	15902	15963.0
3W1 Flufenacet fb sulfosulfuron	11118	11281	11199.5	17371	17564	17467.5
3W2 Flufenacet fb metribuzin	10983	10806	10894.5	16516	16459	16487.5
3W3 Flufenacet fb hand weeding	11843	11565	11704.0	18158	17572	17865.0
3W4 Flufenacet fb weedy check	10498	9997	10247.5	16858	16348	16603.0
4W1 Hand weeding fb sulfosulfuron	11754	11730	11742.0	18871	19308	19089.5
4W2 Hand weeding fb metribuzin	11301	11311	11306.0	17804	18199	18001.5
4W3 Hand weeding fb hand weeding	12265	12008	12136.5	19420	19299	19359.5
4W4 Hand weeding fb weedy check	10795	10836	10815.5	17963	18284	18123.5
5W1 Weedy check fb sulfosulfuron	7584	7565	7574.5	12672	12610	12641.0
5W2 Weedy check fb metribuzin	6942	7234	7088.0	11277	11513	11395.0
5W3 Weedy check fb hand weeding	7895	7928	7911.5	12993	12623	12808.0
5W4 Weedy check fb weedy check	6418	6718	6568.0	11454	11526	11490.0

fb = followed by

Table 31. Economics of cultivation under different treatments in rice

Treatment	Cost of cultivation excluding weeding cost (Rs/ha)	Cost of weed control (Rs/ha)	Total cost of cultivation (Rs/ha)	Grain	Straw	Total	Net return (Rs/ha)	Additional return due to weed control (Rs/ha)	Additional return/ rupee invested on weed control
T ₁ Anilofos 500 g/ha	12945	1112	14057	33182	2852	36034	21977	19914	17.91
T ₂ Pretilachlor 750 g/ha	12945	768	13713	28782	2697	31479	17766	15703	20.44
T ₃ Flufenacet 120 g/ha	12945	480	13425	34075	2869	36944	23519	21456	44.70
T ₄ Hand weeding	12945	2600	15545	36449	3313	39762	24217	22154	8.52
T ₅ Weedy check	12945	-	12945	13637	1371	15008	1371	-	-

Two hand weeding (40 man-days): Rs 2600; Herbicide application (4 man-days): Rs 260; Anilofos (30% EC): Rs 510/l; Pretilachlor (80% EC): Rs 540/l; Flufenacet (60% WP): Rs 1100/kg; Rice grain: Rs 5500/t; Rice straw: Rs 300/t

higher in flufenacet. It was 2 and 5 times higher over pretilachlor and hand weeding, respectively. Additional return per rupee invested on weed control was lower in hand weeding compared to herbicides.

4.4.2 Wheat

Data pertaining to economics of weed control as influenced by different weed control treatments are presented in Table 32.

Net return and additional return per rupee invested on weed control were higher in hand weeding and it proved most economical compared to herbicides. Net return was higher in sulfosulfuron compared to metribuzin. However, additional return per rupee invested on weed control was lower in sulfosulfuron compared to other treatments.

4.4.3 Cropping system

Data pertaining to economics of weed control under different treatments in rice-wheat cropping system are presented in Table 33.

Net return was higher under the treatment combination hand weeding in both rice and wheat (T_4W_3). Next profitable combinations were flufenacet + hand weeding (T_3W_3), hand weeding + sulfosulfuron (T_4W_1) and anilofos + hand weeding (T_1W_3). However, net return per rupee invested was higher in flufenacet + hand weeding (T_3W_3) and flufenacet + metribuzin (T_3W_2).

Table 32. Economics of cultivation under different treatments in wheat

Treatment	Cost of cultivation excluding weeding cost (Rs/ha)	Cost of weed control (Rs/ha)	Total cost of cultivation (Rs/ha)	Grain	Straw	Total	Net return (Rs/ha)	Additional return due to weed control (Rs/ha)	Additional return/ rupee invested on weed control
W ₁ Sulfosulfuron 25 g/ha	9601	2680	12281	31728	3221	34949	22668	4178	1.56
W ₂ Metribuzin 200 g/ha	9601	1100	10701	28898	2773	31671	20970	2480	2.25
W ₃ Hand weeding	9601	2600	12201	33932	3318	37250	25049	6559	2.52
W ₄ Weedy check	9601	-	9601	25305	2786	28091	18490	-	-

Two hand weedings (40 man-days) : Rs 2600; Herbicide spraying (4 man-days): Rs 260; Sulfosulfuron (75% WG): Rs 3270/45 g; Metribuzin (70% WP): Rs 2940/kg; Wheat grain: Rs 6200/t; Wheat straw: Rs 400/t

Table 33. Economics of cultivation under different treatments in rice-wheat cropping system

Treatment	Cost of cultivation excluding weeding cost (Rs/ha)		Cost of weed control (Rs/ha)		Total cost of cultivation (Rs/ha)	Gross return (Rs/ha)				Net return (Rs/ha)	Net return/ rupee invested	
	Rice	Wheat	Rice	Wheat		Grain		Straw				
						Rice	Wheat	Rice	Wheat			
W ₁	12945	9601	1112	2680	26338	33182	32110	2852	3211	71355	45017	1.71
W ₂	12945	9601	1112	1100	24758	33182	28436	2852	2762	67232	42474	1.72
W ₃	12945	9601	1112	2600	26258	33182	33635	2852	3300	72969	46711	1.78
W ₄	12945	9601	1112	-	23658	33182	25082	2852	2760	63876	40218	1.70
W ₁	12945	9601	768	2680	25994	28782	32209	2697	3276	66964	40970	1.58
W ₂	12945	9601	768	1100	24414	28782	29329	2697	2807	63615	39201	1.61
W ₃	12945	9601	768	2600	25914	28782	34044	2697	3349	68872	42958	1.66
W ₄	12945	9601	768	-	23314	28782	24998	2697	2789	59266	35952	1.54
W ₁	12945	9601	480	2680	25706	34075	31025	2869	3162	71131	45425	1.77
W ₂	12945	9601	480	1100	24126	34075	29134	2869	2770	68848	44722	1.85
W ₃	12945	9601	480	2600	25626	34075	34153	2869	3321	74418	48792	1.90
W ₄	12945	9601	480	-	23026	34075	25122	2869	2816	64882	41856	1.82
W ₁	12945	9601	2600	2680	27826	36449	31713	3313	3218	74693	46867	1.68
W ₂	12945	9601	2600	1100	26246	36449	29010	3313	2783	71555	45309	1.73
W ₃	12945	9601	2600	2600	27746	36449	34159	3313	3326	77247	49501	1.78
W ₄	12945	9601	2600	-	25146	36449	25969	3313	2832	68563	43417	1.72
W ₁	12945	9601	-	2680	25226	13637	31589	1371	3228	49825	24599	0.97
W ₂	12945	9601	-	1100	23646	13637	28573	1371	2730	46311	22665	0.96
W ₃	12945	9601	-	2600	25146	13637	33678	1371	3295	51981	26835	1.07
W ₄	12945	9601	-	-	22546	13637	25349	1371	2768	43125	20579	0.91

DISCUSSION

Present investigation was carried out to study the direct and residual effect of herbicides in a rice-wheat cropping system. The experiment was conducted during *kharif* and *rabi* seasons of 2000-01 and 2001-02 at the farm of the Indian Agricultural Research Institute, New Delhi. The experiment with rice was conducted involving three herbicides (anilofos at 500 g/ha, pretilachlor at 750 g/ha and flufenacet at 120 g/ha) along with hand weeding (20 and 40 DAT) and weedy check. Four treatments viz., sulfosulfuron at 25 g/ha, metribuzin at 200 g/ha, hand weeding (30 and 45 DAS) and weedy check were applied to wheat. The experiment was laid out in an extended group design.

In this chapter an earnest attempt has been made to discuss the reasons which may be responsible for some of the important results. As the yield is the final criterion for the evaluation of the efficiency of different treatments, the discussion, therefore, is necessarily centered around the effect of treatments on various characters as they finally modify the yield.

The direct and residual effect of herbicides was assessed in terms of the effect of treatments on weed population and dry matter accumulation. Comparison of the effects of herbicides on crop growth, dry matter accumulation, yield attributes and final grain yield with that of manual weeding provides a reliable measure of the selectivity as well as efficacy of herbicides. The results obtained and presented in previous chapter are discussed in brief in the following pages to derive valid conclusions.

5.1 Rice

5.1.1 Weed flora

The predominant grass weeds that occurred in the field were *Echinochloa crusgalli* and *Echinochloa colona*. Chander and Pandey (2001) and Gopinath and Pandey (2002) also reported preponderance of these two weed species in rice field. Among broadleaf weeds, *Eclipta alba* and *Oxalis corniculata* were prevalent. Singh *et al.* (1997b) and Pandey (2002b) also observed the dominance of *E. alba*.

5.1.2 Weed population

Weed control treatments brought about significant reduction in weed population compared to weedy check. In general, flufenacet gave excellent control of two dominant weed species *Echinochloa crusgalli* and *Echinochloa colona*, thereby recorded lower number of grass weeds. Deege *et al.* (1995) also found excellent control of grasses and sedges with flufenacet. However, in flufenacet significantly higher population of broadleaf weeds was recorded compared to anilofos and hand weeding. Similar was the finding of Deege *et al.* (1995). Comparatively higher number of grass weeds in hand weeding may be attributed to improper weeding due to failure of labourers to distinguish these weeds owing to their morphological similarity to rice plants and recurrence of regrowth and lower number of broadleaf weeds compared to other treatments due to their effective control. Prasad *et al.* (2001) found two hand weedings more efficient than herbicides in reducing weed growth in rice.

In general, pretilachlor was least effective among the weed control treatments both against grass and broadleaf weeds. Poor efficacy of pretilachlor

against weeds particularly broadleaf weeds was reported earlier by Phogat and Pandey (1998).

5.1.3 Dry matter accumulation by weeds

All the weed control treatments resulted in significantly lower dry matter accumulation by weeds (Table 6). In both the years, hand weeding effected significant decrease compared to all other treatments, despite the number of weeds being almost similar in it to that of flufenacet and anilofos. This may be ascribed to presence of very small and thin young weeds, which may have emerged after weeding. The findings of Chander and Pandey (2001) and Prasad *et al.* (2001) was similar. Flufenacet was the next most effective treatment closely followed by anilofos in arresting dry matter accumulation by weeds. These herbicides killed germinating weed seeds and arrested the growth of germinated weeds, thereby resulting in lower dry matter accumulation by weeds. Gopinath and Pandey (2002) also found significant reduction in dry matter accumulation by weeds with flufenacet and it was comparable to butachlor and anilofos. Similar were the findings of Rekha *et al.* (2002.)

5.1.4 Weed index and weed control efficiency

Weed index (62.6%) and weed control efficiency (82.65-93.29%) were highest of hand weeding. Sharma and Roy (1987), Chander and Pandey (2001) and Prasad *et al.* (2001) also found hand weeding the most effective in arresting dry matter accumulation by weeds thereby resulting in higher weed control efficiency compared to herbicides. Flufenacet was the next best treatment which registered marginally higher weed index and weed control efficiency compared to anilofos.

5.1.5 Growth and development of rice

At 30 days stage, in both anilofos and hand weeding plants were of similar height but significantly taller than the plants in flufenacet and pretilachlor (Table 9). Lower height of plants in flufenacet may be attributed to its phytotoxic effect for a fortnight.

At 60 days and at harvest stages, hand weeding registered significantly higher plant height compared to other treatments. The increase was due to decreased weed-crop competition and concomitant better utilization of growth factors by the crop. Lower height of plants in pretilachlor and weedy check may be attributed to severe weed-crop competition and deleterious effect of weeds on crop.

At 30 days stage, in hand weeding lower dry matter accumulation compared to herbicide treatments and lower number of tillers compared to anilofos and flufenacet were recorded. This may be ascribed to initial setback to crop due to severe competition owing to vigorous weed growth till their removal. At later stages (60 DAT and at harvest), however, higher dry matter accumulation and higher number of tillers were recorded in hand weeding due to better crop growth environment owing to elimination of competition due to removal of weeds at early stages. Similar were the findings of Gopinath and Pandey (2002).

5.1.6 Yield attributes

Weed control treatments brought about marked increase in panicles per hill, panicle length, grain weight per panicle and 1000-grain weight both in 2000 and 2001 (Table 12). In general, hand weeding registered higher values for all the yield attributes followed by flufenacet and anilofos. These results indicate that

improvement in yield attributes occur when weeds are controlled in the early stages of crop growth either by chemical means or manually, which scale down competition resulting in congenial environment for better crop growth. Significant increase in the yield attributes due to effective control of weeds was reported by Gogoi (1997), Nandal *et al.* (1999b) and Rajkhowa *et al.* (2001).

5.1.7 Grain and straw yield

Weed control treatments caused significant increase in grain and straw yield (Table 14). In both the years, hand weeding recorded higher yield and proved statistically superior to all other treatments. On an average, the grain yield increase in hand weeding was 167.27% over weedy check. Superiority of hand weeding may be ascribed to lower weed population (Tables 3,4 and 5) and dry matter accumulation by weeds (Table 6) at critical growth stages owing to their removal that facilitated better crop growth, thereby resulting in improvement in yield attributes and crop yield. Similar were the findings of Chander and Pandey (2001), Prasad *et al.* (2001) and Pandey (2002b). Whereas, Nandal *et al.* (1999b) and Rekha (2002) found hand weeding statistically similar to anilofos and butachlor in increasing grain yield.

Flufenacet and anilofos brought about identical increase in grain and straw yield and proved significantly superior to pretilachlor. On an average, the grain yield increase in flufenacet and anilofos was 149.86% and 143.31%, respectively compared to weedy check. Lower increase in yield in pretilachlor may be attributed to its poor efficacy both against grass and broadleaf weeds and marginal increase in crop growth and yield attributes. These results are in

accordance with the findings of Gill *et al.* (1991), Gogoi (1997) and Gopinath and Pandey (2002).

Lower yield in weedy check was due to severe weed-crop competition that resulted in poor growth, development and poor expression of yield attributes particularly number of panicles per hill and grain weight per panicle. The grain yield was lower by 62.58% due to unchecked weed growth. Similar reduction in yield was reported by Nandal *et al.* (1999b), Singh *et al.* (1999b) and Singh *et al.* (2002b).

Weed control treatments resulted in significant increase in harvest index compared to weedy check. The highest index was of flufenacet followed by anilofos and hand weeding.

5.1.8 Herbicide residues in soil and rice grain

Initial deposits of anilofos at 500 g/ha, pretilachlor at 750 g/ha and flufenacet at 120 g/ha in soil ranged between 0.691 to 0.703, 0.928 to 0.932 and 0.114 to 0.106 µg/g, respectively (Table 15). At harvest, however, all the herbicides were below detectable limits both in soil and grain in both the years. This finding is in accordance with the finding of Jayakumar and Sankaran (1995), Radhamani *et al.* (1997) and Rouchaud *et al.* (1998). Fajardo *et al.* (2000) observed leaching and faster degradation of pretilachlor and mefenacet in reductive soil layer (1 to 10 cm) of paddy.

5.2 Wheat

5.2.1 Weed flora

The predominant grass weeds that occurred in the field were *Phalaris minor* and *Avena ludoviciana*. Preponderance of these two weed species in

wheat field were earlier reported by Das and Yaduraju (2002) and Pandey *et al.* (2002a). Among broadleaf weeds, *Coronopus didymus*, *Melilotus indica* and *Rumex* sp. were prevalent. Singh *et al.* (1999d) and Pandey (2002a) also observed the dominance of these three weed species in wheat grown after rice.

5.2.2 Weed population

The residual effect of treatments (applied to rice) was not well pronounced on weed population in succeeding wheat except on broadleaf weeds at 60 days stage in 2000-01. Mishra and Singh (1992) and Singh and Vaishya (1994) did not find any effect of herbicides applied to rice on weeds in succeeding wheat.

The direct effect of weed control treatments was well marked on weed population in both the years. Metribuzin was the most potent and caused significant decrease in the population of both grass and broadleaf weeds. It killed all the broadleaf weeds and completely ceased the growth of both *Phalaris minor* and *Avena ludoviciana*. The latter first turned yellow and gradually died after about 20 days. Similar was the finding of Pandey (2002a). In hand weeding at initial stages significantly higher grass weed population was recorded compared to sulfosulfuron while significantly lower number of broadleaf weeds were recorded in the latter treatment compared to the former. Higher number of grass weeds in hand weeding may be due to failure of the labour to clearly distinguish between wheat and grass weeds owing to their morphological similarity. Ineffectiveness of sulfosulfuron against broadleaf weeds has earlier been reported by Pandey (1999) and Sharma *et al.* (1999).

5.2.3 Dry matter accumulation by weeds

Dry matter accumulation by weeds was not affected due to residual effect of preceding treatments (applied to rice). This may be attributed to non-persistence of herbicides in soil beyond rice harvest (Table 15). Similar was the finding of Singh and Vaishya (1994). They propounded similar reasons.

Direct effect of treatments was well pronounced. All the weed control treatments (applied to wheat) significantly lowered the dry matter accumulation by weeds compared to weedy check. Lower dry matter accumulation by weeds in metribuzin was due to effective control of weeds (Table 16, 17 and 18). This paralyses the vital metabolic processes of emerged weeds viz. photosynthesis, cell division etc. and causes their death. Higher efficacy of metribuzin in arresting the dry matter accumulation by weeds was reported earlier by Chauhan *et al.* (1998), Das and Yaduraju (2002) and Pandey *et al.* (2002a).

Hand weeding gave better control than sulfosulfuron owing to effective removal of weeds at critical periods that resulted in lower population and consequently lower dry matter accumulation. Singh and Saha (2001), Das and Kulshrestha (2002) and Pandey *et al.* (2002b) also found hand weeding more effective in arresting the dry matter accumulation by weeds.

5.2.4 Weed index and weed control efficiency

The higher weed index was of hand weeding (25.42%) closely followed by sulfosulfuron (20.2%). Lower weed index was of metribuzin, despite most effective control of weeds. It may be due to its adverse effect on crop growth, development and grain yield (Table 28).

Weed control efficiency of metribuzin was higher than hand weeding (Table 21). It may be ascribed to marked reduction in weed number and dry matter accumulation in metribuzin at all stages of crop growth. Similar higher weed control efficiency of metribuzin has been reported by Chauhan *et al.* (1998), Balyan *et al.* (1999) and Sardana *et al.* (2001). Lower weed control efficiency of sulfosulfuron compared to hand weeding was reported earlier by Pandey (1999) and Das and Kulshrestha (2002).

5.2.5 Growth and development of wheat

Residual effect of treatments (applied to rice) was not noticeable on any growth parameters like plant population, plant height, dry matter accumulation and number of tillers at any stage either in 2000-01 or in 2001-02. Similar results were reported by number of researchers (Nandal and Singh, 1994a and 1994b; Veerabadran *et al.*, 1994; Balasubramaniam *et al.*, 1999; Janardhan *et al.*, 1999).

Direct effect of treatments on plant height and dry matter accumulation was distinguished in both the years (Tables 23 and 24). Hand weeding effected remarkable increase in plant height and dry matter accumulation compared to other treatments particularly at initial stages. This increase may be due to better crop growth environment created owing to removal of weeds at critical period and concomitantly better utilization of growth factors. Similar increase in plant height and dry matter accumulation in hand weeding was reported by Balyan and Singh (2000) and Pandey *et al.* (2002a and 2002b).

Sulfosulfuron caused slight but temporary growth retardation to wheat and significantly lowered plant height and dry matter accumulation compared to hand weeding at 60 days stage in both the years. The findings of Shukla (1998) and

Balyan and Singh (2001) were similar but Das and Kulshrestha (2002) did not observe any adverse effect of sulfosulfuron on the wheat crop even at 75 g/ha.

At 60 days stage in both the years, metribuzin recorded significantly lower plant height and dry matter accumulation compared to other treatments. This was due to the fact that metribuzin at this dose (200 g/ha) had severe phytotoxic effect on wheat in initial stages. The phytotoxicity resulted in the yellowing of leaves, stunting of crop plants and reduction in the crop density. The crop could not recover fully from adverse effect up to 30 days after spray. Walia *et al.* (2001) observed adverse effect of metribuzin after 131 g/ha. Similar were the findings of Singh *et al.* (1998b) and Pandey (2002a).

Hand weeding effected remarkable increase in number of tillers compared to herbicides (Table 25). This was due to elimination of weeds at critical growth period and congenial environment created for better crop growth. Pandey (2002a) found increase in number of tillers with two hand weedings. Sulfosulfuron and metribuzin reduced the tillering to an extent of 9.77% and 30.04%, respectively compared to hand weeding. Similar adverse effect of these herbicides on tillering was observed by Balyan and Panwar (1998) and Balyan (1999).

5.2.6 Yield attributes

The preceding treatments (applied to rice) had no marked effect on effective tillers (ear bearing tillers), ear length, grain weight per ear and 1000-grain weight (Tables 26 and 27).

The direct effect of weed control treatments (applied to wheat) was evident on all the yield attributes. In general, hand weeding favoured higher

increase in number of effective tillers, ear length, grain weight per ear and 1000-grain weight. This may be attributed to favourable crop growth environment provided owing to elimination of competition at early stages thereby enabling the crop plants to utilize the water, nutrients and light resources in a better way. The findings of Pandey (2002a) and Pandey *et al.* (2002a) were similar. They propounded similar reasons for such an increase. Significantly lower number of effective tillers was recorded in metribuzin compared to sulfosulfuron. This was due to adverse effect of metribuzin on crop growth and development, despite excellent control of dominant weeds. In contrast, metribuzin recorded comparatively higher values for ear length, grain weight per ear and 1000-grain weight compared to sulfosulfuron. Drastic reduction in crop density in metribuzin might have reduced the competition among the crop plants resulting in higher availability of growth factors for the improvement of yield attributes.

Crop-weed competition in weedy check brought about significant reduction in number of effective tillers, ear length, grain weight per ear and 1000-grain weight. Lower values for the yield attributes in weedy check were also recorded by Kumar *et al.* (2000), Sardana (2001b), Das and Yaduraju (2002) and Pandey (2002b).

5.2.7 Grain and straw yield

The treatments applied in rice had no marked effect on grain and straw yield and harvest index either in 2000-01 or 2001-02 (Table 28). Nandal and Singh (1994a and 1994b) did not find any effect of anilofos and pretilachlor applied to rice on the yield of succeeding wheat.

Direct effect of weed control treatments resulted in marked improvement in grain and straw yield in both the years (Table 28). Hand weeding caused highest increase in yield which was significantly superior to all other treatments except sulfosulfuron in 2001-02. This may be attributed to drastic decrease in weed population and dry matter accumulation, thereby better crop growth, increased productive tillers and yield attributes. Similar results were earlier reported by Singh and Singh (1996), Singh and Saha (2001) and Pandey *et al.* (2002a). On an average the grain yield increase in hand weeding was 34.09% over weedy check. The magnitude of yield increase caused by sulfosulfuron and metribuzin was 25.38% and 14.19%, respectively over weedy check. Lower yield in metribuzin may be assigned to its detrimental effect on crop growth (Tables 23 and 24) and effective tillers (Table 26), despite excellent control of the dominant weeds. Similar were the findings of Sardana *et al.* (2001), Singh *et al.* (2001a) and Pandey (2002a). In contrast, Balyan (1999) found metribuzin at 200 and 300 g/ha equivalent to weed free treatment in respect to grain yield.

Lower yield in weedy check was due to severe weed competition that resulted in poor crop growth and development and poor expression of yield attributes. The grain yield reduction was 25.42% due to unchecked weed growth. Similar were the findings of Nanda and Patro (1996), Brar *et al.* (1999), Das and Kulshrestha (2002) and Mishra *et al.* (2002). They observed yield loss variation due to weed infestation between 20 to 51% and ascribed the reason of such loss to low nutrient availability and poor crop expression in presence of weeds.

All the weed control treatments imposed in wheat brought about remarkable improvement in harvest index compared to weedy check. Metribuzin

recorded highest harvest index followed by hand weeding. Higher harvest index of metribuzin may be attributed to its detrimental effect on straw yield than on grain yield. Similar results were reported by Pandey *et al.* (2002a).

5.2.8 Herbicide residues in soil and wheat grain

Initial deposits of sulfosulfuron at 25 g/ha and metribuzin at 200 g/ha in soil ranged between 0.080 to 0.088 and 0.211 to 0.220 µg/g, respectively (Table 29). At harvest, however, both the herbicides were below detectable limits both in soil and grain in both the years. Similar were the findings of Keller and Weber (1995) and Dubey *et al.* (1998).

5.3 Total productivity of cropping system

Hand weeding both in rice and wheat resulted in highest total productivity compared to rest of the treatment combinations (Table 30). This was due to production of higher grain and straw yield by the crops in this treatment combination (Tables 14 and 28) owing to lower competition due to better control of weeds. It resulted in 84.78% and 68.49% increase in grain and straw yield, respectively over weedy check. Hand weeding + sulfosulfuron (T₄W₁) and flufenacet + hand weeding (T₃W₃) were the next best treatment combinations in improving total productivity. Unchecked weed growth in both crops severely affected the total productivity resulting in 45.88% reduction in grain yield.

5.4 Economics of weed control

In rice, net return was highest in hand weeding followed by flufenacet and anilofos. Tomar (1991) also found hand weeding (twice) as the most cost effective treatment and pretilachlor the least in transplanted rice. However, additional return per rupee invested on weed control was highest in flufenacet.

This was due to its low cost, excellent weed control and higher crop yield recorded in this treatment.

In wheat, hand weeding was most economical from the view point of net return per hectare and additional return per rupee invested on weed control. Singh and Saha (2001) reported similar results. Additional return per rupee invested on weed control was lowest in sulfosulfuron due to very high cost of the herbicide.

Hand weeding in both crops gave highest net income over other treatment combinations. This was due to removal of weeds at critical growth periods that facilitated better crop growth, improvement in yield attributes and highest yield. Similar findings were earlier reported by Sharma and Roy (1987) and Mandal (1991). However, net return per rupee invested was higher in flufenacet + hand weeding (T₃W₃). This was due to low cost involved and higher total productivity which were comparable with hand weeding in both crops.

SUMMARY AND CONCLUSIONS

An experiment entitled "**Direct and residual effect of herbicides in a rice-wheat cropping system**" was conducted during *kharif* and *rabi* seasons of 2000-01 and 2001-02 at the farm of the Indian Agricultural Research Institute, New Delhi. The experiment with rice (*kharif*) was conducted involving five weed control treatments viz., anilofos at 500 g/ha, pretilachlor at 750 g/ha, flufenacet at 120 g/ha, hand weeding (20 and 40 DAR) and weedy check. Four treatments viz., sulfosulfuron at 25 g/ha, metribuzin at 200 g/ha, hand weeding (30 and 45 DAS) and weedy check were applied to wheat. The experiment was laid out in an extended group design.

The main objectives were: (i) to study the direct and residual effect of herbicides on crops and weeds, (ii) to study the persistence of herbicides in soil and crop, and (iii) to suggest economically viable weed control measures for rice-wheat cropping system.

The soil of the experimental field was sandy clay loam and slightly alkaline in reaction. It was medium in organic carbon, available phosphorus and potassium.

Observations on weeds were recorded on population and dry matter accumulation at three stages. Observations recorded on crop included growth components (plant height, dry matter accumulation and number of tillers), yield attributes (effective tillers, panicle or ear length, grain weight per panicle or ear and 1000-grain weight) and yield (grain and straw yields). Laboratory analysis was undertaken to study the persistence of herbicides in soil and crop. The salient findings originated from this investigation are briefly summarized below:

6.1 Rice

- (i) In rice, both grass and broadleaf weeds occurred in the field. *Echinochloa crusgalli* and *Echinochloa colona* among the grasses and *Eclipta alba* and *Oxalis corniculata* among broadleaf weeds were dominant.
- (ii) Weed control treatments effected significant decrease in weed population. Hand weeding gave better control of both grass and broadleaf weeds. Flufenacet gave excellent control of *Echinochloa crusgalli*, *Echinochloa colona* and other grass weeds but proved less effective against broadleaf weeds. Pretilachlor was the least effective treatment both against grain and broadleaf weeds.
- (iii) Hand weeding effected significantly higher decrease in dry matter accumulation by weeds. Flufenacet was the next most effective treatment closely followed by anilofos.
- (iv) The weed index and weed control efficiency of hand weeding were the highest while that of pretilachlor the lowest. The values for these parameters of flufenacet and anilofos were identical.
- (v) Weed control measures brought about significant improvement in growth components of rice viz., plant height, dry matter accumulation and number of tillers compared to weedy check. In general, hand weeding was the most effective treatment in augmenting these components. Flufenacet was the next best treatment.
- (vi) Weed control treatments effected significant increase in all the yield attributes over weedy check. In general, hand weeding registered higher values for all the yield attributes followed by flufenacet and anilofos.
- (vii) Hand weeding registered highest grain and straw yield in both the years and proved significantly superior to other treatments. Flufenacet and

anilofos recorded identical increase in grain and straw yield and proved statistically superior to pretilachlor.

- (viii) Weed control treatments resulted in significant increase in harvest index compared to weedy check. It was highest with flufenacet followed by anilofos and hand weeding.
- (ix) All the herbicides applied in rice were below detectable level in soil and grain at harvest of the crop.

6.2 Wheat

- (i) In both the years, grass (72.5%) and broadleaf (27.5%) weeds occurred in wheat field. *Phalaris minor*, *Avena ludoviciana* and *Poa annua* among grasses and *Coronopus didymus*, *Melilotus indica* and *Rumex* sp. among broadleaf weeds were dominant.
- (ii) Residual effect of treatments applied to rice was not well pronounced on weed population and dry matter accumulation in succeeding wheat at any growth stages in both the years. However, at 60 days stage in 2000-01, significantly lower population of broadleaf weeds was recorded in hand weeding compared to weedy check.
- (iii) Weed control treatments (direct effect) caused significant reduction in weed population and dry matter accumulation by weeds. Metribuzin was the most effective against both grass and broadleaf weeds and proved statistically superior to hand weeding and sulfosulfuron. Hand weeding was the next best treatment. Sulfosulfuron brought down the population of grasses but was less effective against broadleaf weeds.
- (iv) Weed index of hand weeding was highest followed by sulfosulfuron. However, weed control efficiency of metribuzin was higher compared to

hand weeding and sulfosulfuron. Hand weeding was the next most effective treatment.

- (v) Residual effect (rice applied treatments) was not noticeable on any growth parameters of wheat such as plant population, plant height, dry matter accumulation and number of tillers at any stage either in 2000-01 or 2001-02.
- (vi) Hand weeding in wheat resulted in remarkable increase in all the growth components of wheat. Sulfosulfuron caused slight but temporary growth retardation to wheat. However, metribuzin had severe phytotoxic effect on wheat resulting in significantly lower plant height, dry matter accumulation and number of tillers compared to hand weeding and sulfosulfuron.
- (vii) Yield attributes of wheat were not affected appreciably due to residual effect (rice applied treatments) in both the years.
- (viii) Direct effect of treatments (applied to wheat) was visible on yield attributes of wheat. In general, hand weeding favoured higher increase in number of effective tillers, ear length, grain weight per ear and 1000-grain weight. Metribuzin was the next best treatment in improving all the yield attributes except number of effective tillers.
- (ix) Grain and straw yield and harvest index of wheat were not affected significantly by residual effect of preceding rice applied treatments.
- (x) Weed control treatments applied to wheat resulted in significant increase in grain and straw yield of wheat compared to weedy check. The grain yield in hand weeding was markedly higher compared to other treatments except sulfosulfuron in 2001-02. Metribuzin recorded significantly lower grain and straw yield compared to other two weed control treatments. On an average, the grain yield increase with hand weeding, sulfosulfuron and

metribuzin were 34.09%, 25.38% and 14.19%, respectively over weedy check.

- (xi) Metribuzin recorded higher value of harvest index in both the years. This treatment was at par with hand weeding but significantly superior to other treatments.
- (xii) The residues of sulfosulfuron and metribuzin were at non-detectable levels in soil and grain at harvest of the crop.

6.3 Total productivity of cropping system

Hand weeding in both rice and wheat caused higher increase in total productivity of cropping system compared to other treatment combinations. Hand weeding + sulfosulfuron (T₄W₁) and flufenacet + hand weeding (T₃W₃) were the next best treatment combinations in augmenting productivity of cropping system.

6.4 Economics of weed control

- (i) In rice, net return was higher in hand weeding while additional return per rupee invested on weed control was higher in flufenacet.
- (ii) In wheat, net return and additional return per rupee invested on weed control were higher in hand weeding and it proved economical compared to herbicide treatments.
- (iii) In rice-wheat cropping system, net return was higher in hand weeding in both crops (T₄W₃). However, net return per rupee invested was higher in flufenacet + hand weeding (T₃W₃) and flufenacet + metribuzin (T₃W₂).

Conclusions

Based on the results of the present investigations, the following conclusions may be drawn:

- (i) Hand weeding gave effective control of both grass and broadleaf weeds. Flufenacet effectively controlled grass weeds but was less effective against broadleaf weeds. Pretilachlor gave poor control of weeds.
- (ii) Herbicides had no adverse effect on growth and development of rice. Flufenacet had slight but temporary phytotoxic effect on rice.
- (iii) Hand weeding resulted in the higher increase in yield of rice. Flufenacet was the next best treatment followed by anilofos.
- (iv) Herbicides applied in the preceding rice had no apparent residual effect on the weed population, dry matter accumulation and yield of succeeding wheat.
- (v) Hand weeding and metribuzin gave effective control of both grass and broadleaf weeds in wheat. Sulfosulfuron effectively controlled grass weeds but proved ineffective against broadleaf weeds.
- (vi) Metribuzin adversely affected growth and yield of wheat. Sulfosulfuron had temporary phytotoxic effect on wheat.
- (vii) Hand weeding improved growth and development, yield attributes and boosted up yield of wheat. Sulfosulfuron was the next best treatment.
- (viii) Residues of all the herbicides were below detectable limits in soil at crop harvest and in grain of both the crops.
- (ix) Hand weeding in both crops resulted in higher net return per hectare but net return per rupee invested was higher in flufenacet + hand weeding and flufenacet + metribuzin.

REFERENCES

- Angiras, N.N. and Rana, S.S. 1998. Integrated weed management in direct-seeded puddle-sprouted rice (*Oryza sativa*). *Indian Journal of Agronomy* **43**(4):644-649.
- Arokiaraj, A., Chandrasekaran, B., Chinnaswami, K.N. and Sankaran, S. 1989. Effect of critical period of crop-weed competition in transplanted rice. *Oryza* **26**(1&2):201-203.
- Bainade, S.S. and Patel, Z.G. 1992. Yield and economics of wheat as affected by weed management practices under south Gujarat conditions. *Annals of Agricultural Research* **13**(1):75-76.
- Balasubramanian, R. 1998. Effect of glyphosate and pre-emergence herbicides on weed control of rice. *Pestology XXII*(3):8-10.
- Balasubramanian, R., Veerabadran, V. and Sankaranarayanan, A.M. 1997. Bio-efficacy of pre-emergence herbicides in lowland rice nursery. *Indian Journal of Weed Science* **29**(1):17-19.
- Balasubramanian, R., Veerabadran, V., Kannathasan, M. 1999. Influence of continuous use of herbicides in rice based system in residue accumulation and on performance of succeeding pulse crop. *Pesticide Research Journal* **11**(2):200-203.
- Balyan, R.S. 1999. Efficacy of sulfosulfuron, tralkoxydim and metribuzin applied alone and tank mix on weeds in wheat. *Indian Journal of Weed Science* **31**(1&2):80-83.
- Balyan, R.S. 2001. Evaluation of new herbicides against mixed weed flora in wheat. *Haryana Journal of Agronomy* **17**(1&2):30-34.
- Balyan, R.S. and Panwar, R.S. 1998. Efficacy of metribuzin and isoproturon applied alone and tank mix on weed control in wheat. *Haryana Journal of Agronomy* **14**(2):196-201.
- Balyan, R.S. and Singh, S. 2000. Sensitivity of wheat cultivars to sulfosulfuron. *Haryana Journal of Agronomy* **16**(1&2):132-134.
- Balyan, R.S., Malik, R.K. and Chauhan, D.R. 1997. Sensitivity of wheat cultivars to metribuzin. *Indian Journal of Weed Science* **29**(1&2):77-78.
- Balyan, R.S., Panwar, R.S., Malik, R.S. and Dhankar, R.S. 1999. Efficacy of new herbicides for weed control in wheat. *Haryana Journal of Agronomy* **15**(1):74-79.

- Barefoot, A.C., Strahan, J.C., Powley, C.R., Shalaby, L.M. and Klemens, F.K. 1995. Analytical methods for sulfonyleureas in environmental samples. In: *Proceedings of Brighton Crop Protection Conference: Weeds*. 20-23 November, 1995, Brighton, U.K. 2:707-712.
- Beyer, E.H. (Jr.), Duffu, M.J., Hay, J.V. and Schlueter, D.D. 1988. Sulfonyleureas. In: *Herbicides: Chemistry, degradation and mode of action* – Kearney, P.C. and Kautmsan, D.D. (eds.). Marcel Dekker, Inc. New York, 3:117-119.
- Bhowmick, M.K., Ghosh, R.K. and Pal, D. 2000. Bio-efficacy of new promising herbicides for weed management in summer rice. *Indian Journal of Weed Science* 32(1):35-38.
- Biswas, J.C., Sattar, S.A. and Bashar, M.K. 1992. Weed competitiveness of upland rice cultivars in Bangladesh. *International Rice Research Newsletter* 17(3):14.
- Bouyoucos, C.J. 1962. Hydrometer method for making particle size analysis of soil. *Agronomy Journal* 55:464-465.
- Brar, L.S., Walia, U.S. and Dhaliwal, B.K. 1999. Bioefficacy of new herbicides for the control resistant *Phalaris minor* in wheat. *Pesticide Research Journal* 11(2):177-180.
- Brinkmann, R. and Dahmen, P. 1997. FOE 5043 and Sencor R used under practical conditions in soybeans and tomatoes in Italy. *Pflanzenschutz-Nachrichten-Bayer* 50(2):175-182.
- Brown, D.F., McCool, D.K., Papendick, R.I. and McDonough, L.M. 1985. Herbicide residues from winter wheat plots: Effect of tillage and crop management. *Journal of Environmental Quality* 14(4):521-532.
- Brown, D.F., McDonough, L.M., McCool, D.K. and Papendick, R.I. 1984. High-performance liquid chromatographic determination of bromoxynil octanoate and metribuzin in runoff water from wheat fields. *Journal of Agricultural and Food Chemistry* 32(2):195-200.
- Chander, S. and Pandey, J. 2001. Effect of rice (*Oryza sativa*) culture, nitrogen and weed control on nitrogen competition between scented rice and weeds. *Indian Journal of Agronomy* 46(1):68-74.
- Chauhan, B.S., Yadav, A. and Malik, R.K. 2001. Competitive wheat genotypes under zero tillage: An important tool to manage resistant *Phalaris minor*. *Indian Journal of Weed Science* 33(1&2):75-76.

- Chauhan, D.S., Sharma, R.K. and Verma, O.S. 1998. Integrated weed management in wheat through tillage options and new molecules under rice-wheat system. In: *Proceedings of an International Conference*, 12-14 August, 1997, Karnal. pp. 263-273.
- Chela, G.S. and Gill, H.S. 1980. Chemical control of *Echinochloa crusgalli* in transplanted rice. *Indian Journal of Weed Science* **12**:7-14.
- Chhokar, R.S., Chauhan, D.S. and Sharma, R.K. 2001a. Time of sulfosulfuron application in wheat for *Phalaris minor* control. *Indian Journal of Weed Science* **33**(1):85-86.
- Chhokar, R.S., Chauhan, D.S., Sharma, R.K. and Singh, R.K. 2001b. Evaluation of fluazolate and sulfosulfuron against weeds in wheat. *Pestology* **25**(8):16-18.
- Chopra, N., Singh, H. and Tripathi, H.P. 1999. Critical period of weed-crop competition in wheat. *Indian Journal of Weed Science* **31**(3&4):151-154.
- Choubey, N.K., Tripathi, R.S. and Ghosh, B.C. 1999. Effect of fertilizer and weed management of direct seeded rice (*Oryza sativa*) on nutrient utilization. *Indian Journal of Agronomy* **44**(2):313-315.
- Conn, J.S. and Cameron, J.S. 1988. Persistence and carry-over of metribuzin and triallate in subarctic soils. *Canadian Journal of Soil Science* **68**(4):827-830.
- Das, T.K. and Kulshrestha, G. 2002. Studies on weed management of wheat. *Pestology* **26**(9):28-31.
- Das, T.K. and Yaduraju, N.T. 2002. Optimization of metribuzin use for controlling isoproturon resistant *Phalaris minor* Retz. in wheat. *Pesticide Research Journal* **14**(1):47-56.
- De, G.C. and Mukhopadhyay, S.K. 1983. Efficacy of granular herbicides in saving the major plant nutrients removal by weeds in transplanted rice. In: *Abstracts of papers. Annual Conference of Indian Society of Weed Science*, Varanasi. p. 10.
- Deege, R., Foster, H., Schmidt, R.R., Thielert, W., Tice, M.A., Jaagesan, G., Bloomberg, J.R. and Santel, H.J. 1995. BAY FOE 5043: A new low rate herbicide for pre-emergence grass control in corn, cereals, soybeans and other selected crops. In: *Proceedings of Brighton Crop Protection Conference: Weeds*. 20-23 November 1995, Brighton, U.K. 1:43-48.
- Dhiman, S.D., Nandal, D.P., Singh, B. and Om, H. 1998. Efficacy of herbicides and their combinations on weed control in scented dwarf rice (*Oryza sativa*). *Indian Journal of Agronomy* **43**(2):295-297.

- DRR, 2000. *Annual Report*. Directorate of Rice Research, Rajendranagar, Hyderabad. pp. 45-46.
- Dubey, P.K., Srivastava, A., Sand, N.K. and Gupta, K.C. 1998. Analysis of metribuzin in soil and grain and straw of wheat by HPLC. *Pesticide Research Journal* **10**(1):101-104.
- Fajardo, F.F., Takagi, K., Ishizaka, M. and Usui, K. 2000. Pattern and rate of dissipation of pretilachlor and Mafenacet in plow layer and paddy water under lowland field conditions: A three year study. *Journal of Pesticide Science* **26**:94-100.
- Forster, H., Schmidt, R.R., Santel, H.J. and Andree, R. 1997. FOE-5043 A new selective herbicide from the oxyacetamide group. *Pflanzenschutz-Nachrichten-Bayer* **50**(2):105-116.
- Gajbhiye, V.T. and Gupta, S. 2001. Adsorption-desorption behaviour of flufenacet in five different soils of India. *Pest Management Science* **57**(7):633-639.
- Gajbhiye, V.T., Gupta, S. and Agnihotri, N.P. 2000. Gas liquid chromatographic method of analysis for a herbicide flufenacet (FOE 5043). *Pesticide Research Journal* **12**(1):41-47.
- Gill, H.S., Walia, U.S. and Brar, L.S. 1978. Control of *Phalaris minor* Retz. and wild oats in wheat with new herbicides. *Pesticides* **12**:55-56.
- Gogoi, A.K. 1997. Relative efficiency of herbicides in lowland transplanted rice. *Annals of Agricultural Research* **18**(4):510-514.
- Gogoi, A.K. 1998. Weed control in late-transplanted, lowland rice (*Oryza sativa*). *Indian Journal of Agronomy* **43**(2):298-301.
- Gogoi, A.K., Rajkhowa, D.J. and Kandali, R. 2000. Effect of varieties and weed control practices on rice (*Oryza sativa*) productivity and weed growth. *Indian Journal of Agronomy* **45**(3):580-585.
- Gopinath, K.A. and Pandey, J. 2002. Evaluation of flufenacet for control of weeds in transplanted rice (*Oryza sativa*). In: *Extended summaries. 2nd International Agronomy Congress, 26-30 November 2002, New Delhi.* **2**:924-926.
- Gupta, S. and Mukherjee, R. 1989. A calculus for factorial arrangements. Lecture Notes in Statistics, Springer Verlag, Berlin.
- Hageman, N.R., Black, S.E., Cramer, G.L., Isakson, P.J., Ryerson, D.K. and Parrish, S.K. 1996. MON 37500: a new selective herbicide to control annual and perennial weeds in wheat. In: *Proceedings of Western Society of Weed Science* **49**:78-82.

- Hooda, I.S. and Agarwal, S.K. 1991. Studies on population and dry matter production of weeds as affected by variation in irrigation, weedicides and fertility levels. *Haryana Journal of Agronomy* **7**(1):63-69.
- Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall Inc. Englewood Cliffs, USA.
- Jain, K.K., Agrawal, K.K. and Naktore, C.L. 1998. Effect of herbicides on weeds, crop growth and energy utilization in transplanted rice. *Indian Journal of Weed Science* **39**(1&2):90-91.
- Janardhan, G. and Muniyappa, T.V. 1994. Economics of some pre-emergence herbicides in transplanted rice. *Current Research* **22**(11&12):154-156.
- Janardhan, G., Muniyappa, T.V., Ramachandra, C., Bhaskar, S. and Krishnamurthy, N. 1999. Residual effect of pre-emergence herbicides applied to transplanted rice on succeeding crops. *Current Research (University of Agricultural Sciences, Bangalore)* **28**(1&2):12-14.
- Jarczyk, H.J. 1983. Method for gas chromatographic determination of sencor residues in plant material, soil and water, with an N-specific detector. *Pflanzenschutz Nachrichten-Bayer* **36**(1):63-72.
- Jayakumar, R. and Anandakrishnan, B. 2001. Studies on the bioefficacy of metsulfuron-methyl for weed control in transplanted rice. *Pestology* **25**(3):32-35.
- Jayakumar, R. and Sankaran, S. 1995. Evaluation of Anilofos 50EC residues in transplanted rice. *Madras Agricultural Journal* **82**(4):296-299.
- Jayakumar, R. and Sreeramulu, U.S. 1993. Degradation and persistence of herbicides in transplanted rice. In: *Proceedings of International Symposium*, 18-20 November, 1993, Hisar, Haryana. II:101-105.
- Johnson, A.B. 2001. Adsorption and degradation of metalochlor and metribuzin in a no-till system under three winter crop covers. *Soil and Sediment Contamination* **10**(5):525-537.
- Johri, A.K., Singh, G. and Sharma, D. 1992. Nutrient uptake by wheat and associated weeds as influenced by management practice. *Tropical Agriculture* **69**:391-393.
- Joy, P.P., Syriac, E.K., Nair, N.P. and Joseph, C.A. 1992. Evaluation of herbicides for transplanting rice in Kerala, India. *International Rice Research Newsletter* **17**(2):29.
- Joy, P.P., Syriac, E.K., Nair, N.P., Nair, P.K.C. and Joseph, C.A. 1991. Weed control economics in transplanted rice (TPR). *International Rice Research Newsletter* **16**(6):26.

- Khan, M. and Saghir, A.R. 1989. Residual activity of triazines and some other herbicides in the soil. *Sarhad Journal of Agriculture* **5**(6):591-595.
- Khare, A. and Jain, H.C. 1995. Relative performance of chemical and cultural weed control methods in transplanted rice. *World Weeds* **2**:147-153.
- Kookana, R.S., Di, H.J. and Aylmore, L.A.G. 1995. A field study of leaching and degradation of nine pesticides in a sandy soil. *Australian Journal of Soil Research* **33**:1019-1130.
- Krausz, R.F., Young, B.G., Kapusta, G. and Mathews, J.L. 2000. Application timing determines giant foxtail (*Setaria faberi*) and barnyardgrass (*Echinochloa crusgalli*) control in no-till corn (*Zea mays*). *Weed Technology* **14**(1):161-166.
- Kulmi, G.S. 1991. Associated weed flora and their susceptibility to herbicides in transplanted rice. *Indian Journal of Agronomy* **36**(1):113-116.
- Kumar, M.D. and Basavaraj, B. 1996. Evaluation of anilophos herbicide for transplanted rice. *Karnataka Journal of Agricultural Sciences* **9**(3):520-522.
- Kumar, S., Malik, R.K., Yadav, A. and Singh, S. 2000. Evaluation of alternate herbicides against resistant *Phalaris minor* in wheat at farmers' field. *Haryana Journal of Agronomy* **16**(1&2):125-127.
- Kumar, S., Tyagi, R.C. and Malik, R.K. 2001. Differential response to sulfosulfuron under different irrigation frequencies to control weeds in wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **46**(3):480-484.
- Kurmi, K. 1993. Comparative efficiency of herbicides in transplanted summer rice (*Oryza sativa*). *Indian Journal of Agronomy* **38**(2):302-303.
- Langeluddeke, P., Salbeck, G., Bieringer, H., Kassebeer, H. and Unglaub, H. 1981. Hoe 30374 – a new herbicide for transplanted paddy rice. In: *Proceedings of the Eighth Asian-Pacific Weed Science Society Conference*: pp.449-454.
- Laubser, J.W. 1998. Activity of chlorsulfuron, ethoxysulfuron and sulfosulfuron towards selected cereal weeds. *Applied Plant Sciences* **12**(2):57-59.
- Lian, H.Z., Zhang, W.B., Jiang, Q. and Mias, J. 1996. Simultaneous, determination of metsulfuron-methyl, chlorsulfuron and bensulfuron-methyl in various formulations of sulfonyleurea herbicides by HPLC-UV detection. *Journal of Liquid Chromatography and Related Technologies* **19**:207-216.

- Madhu, M. and Nanjappa, H.V. 1997. Effect of herbicides on chlorophyll content and grain yield of direct seeded rice under puddle condition. *Indian Journal of Weed Science* **29**(3&4):159-162.
- Mahajan, G. and Brar, L.S. 2001. Studies on herbicide resistance in *Phalaris minor* under Panjab conditions. *Indian Journal of Weed Science* **33**(1&2):1-4.
- Malik, R.K. and Singh, S. 1993. Evolving strategies for herbicides use in wheat: Resistance and integrated weed management. In: *Proceedings of International Symposium, Indian Society of Weed Science*, 18-20 November, 1993, Hisar, India. **1**:225-238.
- Malik, R.K. and Singh, S. 1995. Littleseed canarygrass (*Phalaris minor*) resistance to isoproturon in India. *Weed Technology* **9**:419-425.
- Malik, R.K. and Singh, S. 1996. Potency of anilofos and butachlor applied alone or in combination with 2,4-D against barn yard grass (*Echinochloa crusgalli* (L.) Beauv). *Indian Journal of Weed Science* **28**(1&2):44-47.
- Malik, R.K. and Yadav, A. 1997. Potency of alternate herbicides against isoproturon-resistant littleseed canarygrass. In: *Proceedings of 16th Asian-Pacific Weed Science Society Conference*, 8-12 September, 1997, Kuala Lumpur, Malaysia. pp. 208-210.
- Malik, R.S., Yadav, A., Malik, R.K. and Balyan, R.S. 2000a. Effect of nitrogen and sulfosulfuron against *Chenopodium album* and *Rumex retroflex* in wheat. *Haryana Journal of Agronomy* **16**(1&2):44-47.
- Malik, R.S., Yadav, A., Malik, R.K. and Banga, R.S. 2000b. Effect of tank mix spray of herbicides and fertilizers against weeds in wheat. *Haryana Journal of Agronomy* **16**(1&2):40-43.
- Mandal, N.N. 1991. Weed control in rice-wheat sequence of cropping. *Bangladesh Journal of Agricultural Sciences* **19**(1):55-58.
- Mathew, J. and Jagadeeshkumar, T.N. 1999. Chemical weeding strategies with improved crop safety in direct seeded puddled rice. *Oryza* **36**(4):355-357.
- Mishra, J.S., Yaduraju, N.T., Singh, V.P. and Moorthy, B.T.S. 2002. Effect of tillage and herbicides on weeds in wheat (*Triticum aestivum*) under transplanted rice (*Oryza sativa*)-wheat system. In: *Extended summaries. 2nd International Agronomy Congress*, 26-30 November, 2002, New Delhi. **2**:952-953.
- Mishra, O.P. and Singh, J.N. 1992. In: *Abstracts of Papers. Annual Weed Science Conference*. p. 147.

- Moody, K. 1977. In: *Proceedings of Sixth Asian-Pacific Weed Science Society Conference* pp. 11-17.
- Mukhopadhyay, S.K., Bera, P.S. and De, G.C. 1985. Weed-crop competition in rice *kharif* transplanted and what crops in lateritic belt of West Bengal. In: *Abstracts of papers. Annual Conference of Indian Society of Weed Science*, pp. 83-84.
- Munegowda, M.K., Nagaraju, A.P., Varadaraju and Krishnamurthy, K. 1990. Efficacy of anilophos at different rates and time of application on weed control in transplanted rice. *Current Research (University of Agricultural Sciences, Bangalore)* **19**(9):145-146.
- Nanda, S.S. and Patro, G.K. 1996. Effect of weed management practices, row spacings and fertilizer levels on growth and yield of wheat. *Indian Journal of Weed Science* **28**(1&2):67-69.
- Nandal, D.P. and Singh, C.M. 1994a. Economics of weed management in rice-wheat cropping system. *Himachal Journal of Agricultural Research* **20**(1&2):16-21.
- Nandal, D.P. and Singh, C.M. 1994b. Weed management in transplanted rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **39**(4):517-521.
- Nandal, D.P., Om, H. and Dhiman, S.D. 1999a. Management of weeds with herbicides in transplanted rice. *Indian Journal of Weed Science* **31**(1&2):75-77.
- Nandal, D.P., Om, H. and Dhiman, S.D. 1999b. Efficacy of herbicides applied alone and in combinations against weeds in transplanted rice. *Indian Journal of Weed Science* **31**(3&4):239-242.
- Narayanan, A., Poonguzhalan, R., Mohan, R., Mohan, J.R., Suburayalu, E. and Hanifa, A.M. 2001. Chemical weed management in transplanted rice in Karaikal region of Pondicherry Union Territory. *Madras Agricultural Journal* **87**(10&12):691-692.
- Nepalia, V. and Kanojia, Y. 2002. Effect of herbicidal weed control on productivity of wheat (*Triticum aestivum*). In: *Extended summaries. 2nd International Agronomy Congress*, 26-30 November, 2002, New Delhi. **2**:1114-1115.
- Nilsson, H. 1991. Herbicide persistence and mobility in arable land. Investigations during 1988-89. In: *Proceedings of Swedish Crop Protection Conference on Weeds and Weed Control* **32**:311-322.
- Pandey, J. 1999. Chemical weed control in wheat. In: *Annual Report, 1998-99, Division of Agronomy, IARI, New Delhi*. pp. 44-45.

- Pandey, J. 2002a. Effect of dose and mode of metribuzin application on *Phalaris minor* and yield of wheat (*Triticum aestivum*). *Indian Journal of Agricultural Sciences* **72**(1):11-13.
- Pandey, J. 2002b. Direct and residual effect of herbicides on weeds and productivity of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. In: *Extended summaries. 2nd International Agronomy Congress*, 26-30 November, 2002, New Delhi. **2**:1166-1167.
- Pandey, J. and Singh, R.P. 1997. Weed control in wheat is key to higher production. *Indian Farming* **47**(8):4-7.
- Pandey, J. and Thakur, K.N. 1988. Effect of herbicides and nitrogen on nutrient removal by weeds in transplanted rice. *Indian Journal of Agronomy* **33**(4):359-363.
- Pandey, J., Gopinath, K.A. and Verma, A.K. 2002a. Investigation on low doses of atrazine, metribuzin and pendimethalin on weeds and yield of wheat. *Acta Agronomica Hungarica* **50**(4):441-445.
- Pandey, J., Gopinath, K.A. and Verma, A.K. 2002b. Effect of dose and time of chlorsulfuron application on weeds and yield of wheat. *Journal of Indian Agriculture and Weed Science* **1**(1):7-9.
- Pandey, J., Singh, R.P. and Shukla, K. 1991. Study on the chemical weed control in upland rice. *Indian Journal of Weed Science* **23**(1&2):7-9.
- Paradkar, N.R., Kurchania, S.P. and Tiwari, J.P. 1997. Chemical control of *Parthenium hysterophorus* L. and other associated weeds in upland drilled rice. *Indian Journal of Weed Science* **29**(3&4):151-154.
- Parrish, S.K., Kaufmann, J.E., Croon, K.A., Ishida, Y., Ohta, K. and Itoh, S. 1995. MON 37500: a new selective herbicide to control annual and perennial weeds in wheat. In: *Proceedings of Brighton Crop Protection Conference: Weeds*. 20-23 November, 1995, Brighton, U.K. **1**:57-63.
- Patel, Z.G., Patel, C.L., Desai, R.M. and Patel, R.B. 1988. Integrated weed management in lowland transplanted rice. *Indian Journal of Weed Science* **20**(1&2):88-89.
- Phogat, B.S. and Pandey, J. 1998. Effect of water regime and weed control on weed flora and yield of transplanted rice (*Oryza sativa*). *Indian Journal of Agronomy* **43**(1):77-81.
- Pillai, K.G. and Rao, M.V. 1974. Current status of herbicide research on rice in India. Paper presented at the *International Rice Research Conference*, IRRI, Manila, the Philippines.

- Piper, C.S. 1950. *Soil and Plant Analysis*. The University of Adelaide, Australia.
- Powley, C.R. and Bernard, P.A. 1998. Screening methods for nine sulfonylurea herbicides in soil and water by liquid chromatography with ultraviolet detection. *Journal of Agricultural and Food Chemistry* **36**:63-69.
- Prasad, K. 1995. Weed management in transplanted rice (*Oryza sativa*). *Journal of Research, Birsa Agricultural University* **7**(1):53-55.
- Prasad, R., Gupta, V.K. and Khanduri, O.P. 2000. Cataloguing in construction of variance balanced block designs: computer algorithms for construction. Project Report, IASRI, New Delhi.
- Prasad, S.M., Mishra, S.S. and Singh, S.J. 2001. Effect of establishment methods, fertility levels and weed management practices on rice (*Oryza sativa*). *Indian Journal of Agronomy* **46**(2):216-221.
- Radhamani, S., Sankaran, S. and Jayakumar, R. 1997. Degradation and persistence of herbicides in direct seeded puddled rice. *Madras Agriculture Journal* **84**(4):194-196.
- Rai, A.K., Chhonkar, P.K. and Agnihotri, N.P. 1998. Adospriton-Desorption of Anilofos on six diverse soils. *Pesticide Research Journal* **10**(2):172-177.
- Rai, A.K., Chhonkar, P.K. and Agnihotri, N.P. 1999. Degradation of pendimethalin and anilofos by enrichment cultures from different soils. *Pesticide Research Journal* **11**(2):127-131.
- Rajkhowa, D.J., Gogoi, A.K. and Kandali, R. 2001. Effect of weed control and nutrient management practices in rice. *Indian Journal of Weed Science* **33**(1&2):41-45.
- Raju, R.A. and Reddy, M.N. 1995. Performance of herbicide mixtures for weed control in transplanted (*Oryza sativa* L.). *Indian Journal of Weed Science* **27**(1&2):106-107.
- Rammohan, J., Narayanan, A.L., Poonguzhalan, R., Mohan, R. and Hanifa, A.M. 1999. Efficacy of pre-emergence herbicides for weed control in lowland transplanted rice in the coastal saline soils. *Indian Journal of Weed Science* **31**(3&4):142-144.
- Ramsak, A. 2001. Flufenacet (Terano, Axiom, Plateen): a new type of broad-leaf and grass weed control. In: *Proceedings of the 5th Slovenian Conference on Plant Protection*, 6-8 March 2001. pp. 404-408.
- Rathore, P.S., Bhatia, D.S. and Mali, A.S. 1990. Effect of weed control measures on growth and yield of cumin. *Indian Journal of Agronomy* **35**(2):304-305.

- Ravi, V., Krishnasamy, S.M. and Ganesamurthy, K. 2001. Evaluation of anilofos in rice weed control. *Madras Agricultural Journal* **87**(1):10-12.
- Reddy, B.G.M., Kumar, M.D., Basappa, K.S.C. and Patil, S.G. 1995. Evaluation of anilofos plus in *kharif* transplanted rice. *Indian Journal of Weed Science* **27**(1&2):108-109.
- Reddy, C.N., Reddy, M.D. and Devi, M.P. 2000. Evaluation of fenoxypop-p-ethyl and ethoxysulfuron in transplanted rice. *Indian Journal of Weed Science* **32**(1&2):105-107.
- Rekha, K.B., Raju, M.S. and Reddy, M.D. 2002. Effect of herbicides in transplanted rice. *Indian Journal of Weed Science* **34**(1&2):123-125.
- Rouchaud, J., Neus, O., Cools, K. and Bulcke, R. 1999. Flufenacet soil persistence and mobility in corn and wheat crops. *Bulletin of Environmental Contamination and Toxicology* **63**:460-466.
- Rouchaud, J., Neus, O., Eelen, H. and Bulcke, R. 2001. Persistence, mobility and adsorption of the herbicide flufenacet in the soil of winter wheat crops. *Bulletin of Environmental Contamination and Toxicology* **67**(4):609-616.
- Saini, J.P. and Singh, K.P. 2001. Efficacy of new herbicides against grass weeds in wheat (*Triticum aestivum*) under mid-hill conditions of Himachal Pradesh. *Indian Journal of Agronomy* **46**(2):233-238.
- Sankaran, S., Jayakumar, R. and Kempuchetty, N. 1993. *Herbicide residues*. Gandhi Book House, Coimbatore. pp. 138-142, 191-195.
- Sardana, V. 2001a. Efficacy of herbicides applied alone and in tank mixture with isoproturon against wild oat (*Avena ludoviciana*) and broad-leaf weeds in wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **46**(4):689-697.
- Sardana, V. 2001b. Evaluation of herbicides for control of weeds in durum wheat (*Triticum durum*). *Indian Journal of Agricultural Sciences* **71**(9):602-604.
- Sardana, V., Walia, U.S. and Mahajan, G. 2001. Management of broad leaf weeds in wheat (*Triticum aestivum* L.). *Indian Journal of Weed Science* **33**(1&2):69-71.
- Sharma, B.D., Nanwal, R.K. and Panwar, R.S. 1999. Evaluation of herbicides for weed control in wheat (*Triticum aestivum*). *Indian Journal of Weed Science* **31**(1&2):99-100.
- Sharma, K.K., Verma, S.P. and Singh, C.M. 1985. Cultural and chemical manipulations for weed management in wheat with reference to grassy weeds. *Tropical Pest Management* **31**:133-138.

- Sharma, R.P. and Roy, R.K. 1987. Studies on weed control methods in rice-wheat rotation. *Annals of Agricultural Research* **8**(2):207-213.
- Shinn, S.L., Thill, D.C., Price, J.W. and Ball, D.A. 1998. Response of downy brome (*Bromus tectorum*) and rotational crops to MON 37500. *Weed Technology* **12**:690-698.
- Shukla, G. 1998. Mon 37500: Candidate herbicide for warm wheat growing environment. In: *Proceedings of International Conference*, 12-14 August 1997, Karnal. pp. 297-301.
- Singh, D. and Singh, Y. 1996. Weed management in different rice cultures and their effects on wheat grown in rice-wheat sequence. *Indian Journal of Weed Science* **28**(1&2):30-35.
- Singh, G., Singh, B.B., Agarwal, R.L. and Nayak, R. 2000. Effect of herbicidal weed management in direct-seeded rice (*Oryza sativa*) and its residual effect on succeeding lentil (*Lens culinaris*). *Indian Journal of Agronomy* **43**(3):470-476.
- Singh, G., Singh, O.M. and Singh, G. 1993. Chemical weed control in lowland transplanted rice under puddled condition. **14**(2):229-231.
- Singh, G., Singh, R.K., Singh, V.P., Nayak, R. and Singh, R.S. 1999a. Weed management in transplanted rice (*Oryza sativa*) under rainfed, lowland situation. *Indian Journal of Agronomy* **44**(4):728-732.
- Singh, G., Singh, R.K., Singh, V.P., Singh, B.B. and Nayak, R. 1999b. Effect of crop-weed competition on yield and nutrient uptake by direct-seeded rice (*Oryza sativa*) in rainfed lowland situation. *Indian Journal of Agronomy* **44**(4):722-727.
- Singh, G., Singh, Y., Singh, V.P., Singh, R.K. and Saxena, A. 2002a. Bioefficiency of herbicides in zero-till wheat in rice-wheat cropping system. *Indian Journal of Weed Science* **34**(1&2):5-8.
- Singh, H., Hooda, R.S., Malik, R.K. and Yadav, A.K. 1999c. Performance of metribuzin, atrazine, trifluralin and their combinations with isoproturon against weeds in wheat. *Crop Research* **17**(3):282-285.
- Singh, J., Malik, R.K. and Amarjeet 2001a. Effect of herbicides and seed rates on wheat yield. *Haryana Journal of Agronomy* **17**(1&2):162-163.
- Singh, K.K. and Kharwara, P.C. 1984. Chemical weed control in transplanted rice under mid-hill conditions. In: *Abstracts of papers. Annual Conference of Indian Society of Weed Science*, Varanasi. p. 13.

- Singh, P.K., Dixit, A., Singh, V.P. and Yaudraju, N.T. 2002b. Demonstration of promising herbicides in rice (*Oryza sativa*) on farmers' fields. In: *Extended summaries. 2nd International Agronomy Congress, 26-30 November, 2002, New Delhi. 2:1442-1443.*
- Singh, P.K., Mishra, J.S., Singh, V.P., Dixit, A. and Yaduraju, N.T. 2001b. Bridging yield gap of wheat through demonstrations on weed control technology at farmers fields. *Pestology 25(7):7-10.*
- Singh, R., Singh, B.B., Singh, G. and Tripathi, S.S. 1999d. Evaluation of metribuzin for *Phalaris minor* control in wheat. *Indian Journal of Weed Science 31(3&4):155-157.*
- Singh, R.D. 1992. Studies on crop weed competition and chemical weed control for rice in Sikkim. *Indian Journal of Hill Farming 5(2):107-111.*
- Singh, S. and Bhan, V.M. 1998. Performance of sulfonyl urea herbicides on weed control in transplanted rice. *Annals of Plant Protection Sciences 6(1):89-91.*
- Singh, S. and Malik, R.K. 1992. Weed management and fertilizer utilization. *Fertilizer News 37:59-63.*
- Singh, S., Kirkwood, R.C. and Marshall, G. 1998a. Effect of ABT on the activity and rate of degradation of isoproturon in resistant biotype of *Phalaris minor* and wheat. *Pesticide Science 53:123-132.*
- Singh, S., Malik, R.K. and Singh, V. 1998b. Evaluation of fenoxaprop against *Phalaris minor* in wheat. *Indian Journal of Weed Science 30(3 & 4):176-178.*
- Singh, S., Malik, R.K., Balyan, R.S. and Singh, S. 1995. Distribution of weed flora of wheat in Haryana. *Indian Journal of Weed Science 27(1&2):114-121.*
- Singh, S., Malik, R.K., Pal, D., Agarwal, S.K., Singh, S. and Pal, D. 1996. Effect of anilofos and its combination with 2,4-D on weed control in transplanted rice. *Haryana Agricultural University Journal of Research 26(20):109-111.*
- Singh, S., Singh, G. and Vashist, R. 1984. Chemical weed control to economise fertilizer use in wheat. 1. Weed flora population, dry matter accumulation and uptake of nitrogen by weeds and wheat. *Indian Journal of Agronomy 29(4):429-435.*
- Singh, S., Singh, T. and Mehra, S.P. 2002c. Efficacy of pyrazosulfuron-ethyl for weed control in transplanted rice (*Oryza sativa*). In: *Extended summaries. 2nd International Agronomy Congress, 26-30 November, 2002, New Delhi. 2:928-929.*

- Singh, S., Singh, V. and Malik, R.K. 1997a. Evaluation of pretilachlor and cyhalofop-butyl in transplanted rice. *Indian Journal of Weed Science* **29**(1&2):71-72.
- Singh, S., Singh, V. and Malik, R.K. 1997b. Performance of tank mixture of chlorimuron and anilofos to control weeds in transplanted rice. *Indian Journal of Weed Science* **29**(1&2):15-16.
- Singh, S.K. and Saha, G.P. 2001. Productivity and profitability of wheat (*Triticum aestivum*) as influenced by cultural and chemical weed control. *Indian Journal of Agronomy* **46**(3):475-479.
- Singh, S.S. and Vaishya, R.D. 1994. Studies on residual effect of herbicides applied in transplanted rice on succeeding wheat crop. *Indian Journal of Weed Science* **26**(3&4):129-131.
- Singh, T., Singh, S. and Bhatia, R.K. 2002d. Weed dynamics in transplanted rice (*Oryza sativa*) due to continuous rotational use of herbicides under rice-wheat (*Triticum aestivum*) cropping system. In: *Extended summaries. 2nd International Agronomy Congress*, 26-30 November, 2002, New Delhi. **2**:963-964.
- Singh, V., Singh, S. and Malik, R.K. 1997c. Effect of tank mix of anilofos and metsulfuron on weed control in transplanted rice. *Indian Journal of Weed Science* **29**(3&4):98-99.
- Singh, Y., Bhardwaj, A.K., Singh, R.K., Singh, G., Kumar, A., Singh, S.P. and Singh, R.K. 2002e. On-farm weed control in rice (*Oryza sativa*) for higher production in mid western U.P. *Indian Journal of Weed Science* **34**(1&2):126-127.
- Sorenson, B.A., Shea, P.J. and Roeth, F.W. 1991. Effects of tillage, application time and rate on metribuzin dissipation. *Weed Research* **31**(6):333-345.
- Stanley, C.W. and Schumann, S.A. 1969. *Chemagro Report No.* 25848.
- Thakur, R.B., Jha, G. and Choudhary, S.K. 1995. Economics of weed control in transplanted rice. *Journal of Applied Biology* **5**(1&2):75-76.
- Thornton, J.S. and Stanley, C.W. 1977. Gas chromatographic determination of sencor and metabolites in crops and soil. *Journal of Agricultural and Food Chemistry* **25**(2):380-386.
- Tomar, S.S. 1987. Herbicides to control weeds in transplanted rice. *International Rice Research Newsletter* **12**(3):38-39.
- Tomar, S.S. 1991. Agronomic and economic evaluation of herbicides in transplanted rice. *International Rice Research Newsletter* **16**(2):24.

- Tonogai, Y., Tsumura, Y., Nakamura, Y. and Shibata, T. 1996. A rapid analysis of triazine herbicides in agricultural products by GC. *Journal of the Food-Hygienic-Society-of Japan* **37**(6):363-371.
- Turbey, R.K., Bethem, R.A. and Peterson, B. 1998. Degradation and mobility of sulfometuron-methyl (oust herbicide) in field soil. *Journal of Agricultural and Food Chemistry* **46**:2360-2367.
- Walia, U.S., Brar, L.S., Kumar, B., Jand, S. and Uppal, R.S. 2001. Performance of metribuzin and atrazine for the control of *Phalaris minor* Retz. in wheat. *Environment and Ecology* **19**(4):965-968.
- Walia, U.S., Kaur, R., Kler, D.S. 2000. Determining residual effect of new herbicides applied to control *Phalaris minor* from wheat on the succeeding crops through bioassay. *Environment and Ecology* **18**(1):130-133.
- Walker, A., Cotterill, E.G. and Welch, S.J. 1989. Adsorption and degradation of chlorsulfuron and metsulfuron-methyl in soils from different depths. *Weed Research* **29**:281-287.
- Weise, A.F., Wood, M.L. and Chenault, E.W. 1988. Persistence of sulfonylurea in Pullusan clay loam. *Weed Technology* **2**:251-256.
- Yadav, S.K., Kumar, A. and Bhan, V.M. 1986. Nutrient uptake in wheat as influenced by herbicides. *Indian Journal of Weed Science* **18**(1&2):60-62.

Appendix I

Mean weekly meteorological data

Standard week	Temperature (°C)		Relative humidity		Total rainfall (mm)	Sunshine hours/day	Evaporation (mm/day)	
	Max.	Min.	Max.	Min.				
Kharif and rabi, 2000-01								
June	23	32.8	24.7	82	67	35.0	5.5	5.6
	24	37.4	27.0	67	41	15.4	4.6	6.2
	25	37.9	27.2	78	48	0.6	6.3	6.8
	26	37.4	28.2	65	58	56.7	1.5	5.9
July	27	35.0	27.1	82	61	66.2	5.7	5.1
	28	33.5	26.7	87	71	11.7	3.5	5.0
	29	32.0	25.3	92	79	104.2	2.8	3.4
	30	32.0	25.8	87	69	36.7	2.8	3.3
Aug.	31	32.9	26.5	75	53	53.0	3.8	4.7
	32	35.1	37.5	73	64	1.0	5.1	4.6
	33	33.1	26.1	83	73	70.5	4.8	3.6
	34	33.1	25.6	90	74	150.2	3.5	3.4
Sept.	35	34.2	26.2	85	62	47.9	2.8	3.5
	36	34.5	24.7	79	67	23.0	1.4	4.4
	37	34.1	25.2	78	56	5.0	7.6	5.7
	38	34.4	22.8	80	54	-	8.4	4.9
	39	33.6	20.8	78	54	1.8	8.0	4.2
Oct.	40	34.7	22.2	85	59	-	8.2	5.2
	41	35.0	16.5	77	40	-	5.5	4.5
	42	35.0	18.5	81	35	-	6.2	4.9
	43	32.8	15.2	86	52	-	6.4	4.0
	44	27.3	15.6	88	44	-	6.4	3.8
Nov.	45	32.1	14.2	86	35	-	7.1	3.5
	46	29.8	11.8	78	33	-	6.3	3.3
	47	27.6	13.0	92	51	-	2.3	2.3
	48	24.1	7.0	84	41	0.8	4.2	2.7
Dec.	49	24.9	5.0	82	35	-	7.0	3.5
	50	23.7	5.8	84	37	-	5.7	3.0
	51	24.7	7.9	88	39	-	5.0	3.1
	52	22.3	5.4	89	42	4.0	4.1	1.9

Contd.....

Appendix I (contd.....)

Standard week		Temperature (°C)		Relative humidity		Total rainfall (mm)	Sunshine hours/day	Evaporation (mm/day)
		Max.	Min.	Max.	Min.			
Jan.	1	15.5	7.7	93	72	18.8	1.8	1.7
	2	16.1	3.2	92	57	0.0	3.7	1.4
	3	18.4	2.8	89	4.2	0.0	4.9	1.8
	4	21.0	7.2	75	4.4	-	5.4	2.8
	5	23.0	6.1	78	36	-	7.0	3.4
Feb.	6	23.4	7.6	79	30	-	7.9	4.1
	7	24.7	7.8	80	47	-	4.0	2.8
	8	26.9	12.1	89	45	12.0	5.1	4.0
	9	25.6	9.5	83	38	-	5.9	3.9
March	10	27.7	9.0	78	30	-	8.4	4.5
	11	21.5	14.2	65	34	-	7.5	6.5
	12	30.7	14.6	72	37	-	7.2	5.9
	13	31.4	15.6	78	42	3.0	7.2	5.1
April	14	33.0	15.6	73	40	-	9.1	6.2
	15	36.6	20.7	62	32	4.8	6.1	6.9
	16	36.4	24.0	71	47	30.8	4.8	6.9
	17	38.5	25.5	60	30	6.6	7.2	8.2

Appendix I (contd...)

Standard week	Temperature ($^{\circ}\text{C}$)		Relative humidity		Total rainfall (mm)	Sunshine hours/day	Evaporation (mm/day)	
	Max.	Min.	Max.	Min.				
Kharif and rabi, 2001-02								
June	23	36.0	24.0	78	50	50.8	7.0	6.8
	24	34.1	23.5	83	59	61.5	6.4	5.3
	25	35.3	27.8	73	68	51.2	6.9	5.6
	26	35.0	26.7	80	58	3.8	5.5	6.4
July	27	33.3	26.0	88	65	38.7	5.1	4.2
	28	34.5	27.9	80	70	60.6	6.9	4.6
	29	33.0	26.9	90	74	63.2	2.5	3.4
	30	33.6	26.8	90	74	28.4	4.9	3.5
Aug.	31	34.1	26.6	79	59	7.2	6.1	5.6
	32	34.2	26.8	88	70	51.2	6.3	4.0
	33	32.9	26.3	87	74	49.8	5.0	3.8
	34	34.9	26.8	74	57	1.8	8.6	6.4
Sept.	35	36.2	27.2	68	54	-	8.4	7.1
	36	35.2	25.2	75	53	77.0	7.8	6.0
	37	35.4	25.1	69	47	0.4	8.5	6.2
	38	35.1	21.9	70	30	-	9.2	7.1
	39	36.2	21.5	66	37	-	9.0	6.2
Oct.	40	32.7	22.9	88	51	18.2	6.1	4.3
	41	34.3	17.3	74	40	-	7.4	3.5
	42	33.2	15.2	76	26	-	6.7	3.9
	43	33.7	17.7	83	28	-	5.9	3.1
	44	34.4	16.9	72	29	-	6.5	3.2
Nov.	45	29.3	12.7	77	32	0.5	6.3	3.2
	46	28.6	10.4	82	29	-	9.7	2.7
	47	27.6	9.2	76	26	-	6.4	2.5
	48	25.7	8.8	77	29	-	5.3	2.2
Dec.	49	26.1	8.5	79	27	0.0	6.4	2.5
	50	22.6	9.8	88	50	0.0	4.5	2.1
	51	21.8	7.3	91	39	0.0	5.6	2.4
	52	22.8	6.3	109	59	0.0	3.5	1.9

Contd

Appendix I (contd.....)

Standard week		Temperature (°C)		Relative humidity		Total rainfall (mm)	Sunshine hours/day	Evaporation (mm/day)
		Max.	Min.	Max.	Min.			
Jan.	1	19.1	3.0	93	48	-	3.1	1.6
	2	21.3	6.7	88	46	-	4.6	1.9
	3	18.2	8.9	87	67	5.6	1.6	1.9
	4	19.7	6.9	83	52	-	5.2	2.8
	5	20.3	3.7	85	34	-	6.2	2.9
Feb.	6	20.8	6.8	83	54	8.4	5.9	2.5
	7	21.4	8.5	90	48	4.8	4.3	2.6
	8	27.2	11.7	75	38	1.0	4.6	3.6
	9	23.9	11.8	82	55	-	5.5	3.4
March	10	27.0	12.0	72	32	-	9.0	4.6
	11	29.1	12.0	72	28	-	8.5	5.3
	12	33.8	13.4	72	30	-	9.1	6.3
	13	33.9	16.9	61	25	-	9.4	6.0
April	14	35.9	17.7	52	28	-	7.1	6.5
	15	36.5	19.0	53	27	-	8.6	7.3
	16	40.6	24.9	42.8	20.2	-	8.6	8.0
	17	40.0	24.2	57	26	-	6.5	7.0

Appendix III. Cost of cultivation of rice

Particulars	Input (per ha)*	Rate (Rs)	Total cost (Rs/ha)*
A. Raising of nursery (1000 m²)			
1. Land preparation			
(i) Ploughing	1 tractor-hr	70/hr	70.00
(ii) Puddling	1 tractor-hr	70/hr	70.00
(iii) Preparation of beds	2 man-days	65/man-day	130.00
2. Seed and sowing			
(i) Seed (Pusa 44)	40 kg	13/kg	520.00
(ii) Sowing	2 man-days	65/man-day	130.00
3. Fertilizers and their application			
(i) Urea	30 kg	4.6/kg	138.00
(ii) Single superphosphate	18 kg	3.2/kg	58.00
(iii) Muriate of potash	6 kg	4.2/kg	25.00
(iv) Fertilizer application	1 man-day	65/man-day	65.00
4. Hand weeding	1 man-day	65/man-day	65.00
5. Irrigation and cost of application	3 times 1 man-day	200/irrigation/ ha 65/man-day	60.00 65.00
6. Rental value of field	2 months	3000/ha/yr	50.00
B. Main field			
1. Land preparation			
(i) Ploughing	8 tractor-hrs	70/hr	560.00
(ii) Puddling and planking	5 tractor-hrs	70/hr	350.00
(iii) Bunding	4 man-days	65/man-day	260.00
2. Uprooting seedlings and transplanting	20 man-days	65/man-day	1300.00
3. Gap filling	3 man-days	65/man-day	195.00

Contd.....

Contd.....

Particulars	Input (per ha)*	Rate (Rs)	Total cost (Rs/ha)*
4. Fertilizers and their application			
(i) Urea	217 kg	4.6/kg	998.00
(ii) Single superphosphate	375 kg	3.2/kg	1200.00
(iii) Muriate of potash	67 kg	4.2/kg	281.00
(iv) Fertilizer application	3 man-days	65/man-day	195.00
5. Irrigation and cost of application			
	10 times	200/irrigation/ ha	2000.00
	10 man-days	65/man-day	650.00
6. Insecticide application			
(i) Endosulfan	1.5 litre	300/litre	450.00
(ii) Cost of spraying	4 man-days	65/man-day	260.00
7. Harvesting, threshing and cleaning			
	20 man-days	65/man-day	1300.00
8. Land rent			
	6 months	3000/ha/yr	1500.00
Grand total			Rs.12945.00

*Rs/0.1 ha for raising of nursery except cost of seed

Prevailing prices of produce (Pusa 44)

Grain: Rs. 5500/t

Straw: Rs. 300/t

Appendix IV. Cost of cultivation of wheat

Particulars	Input (per ha)	Rate (Rs)	Total cost (Rs/ha)
1. Land preparation			
(i) Ploughing	5 tractor-hrs	70/hr	350.00
(ii) Discing and planking	3 tractor-hrs	70/hr	210.00
(iii) Field layout	2 man-days	65/man-day	130.00
2. Seed and sowing			
(i) Seed (HD 2285)	100 kg	15/kg	1500.00
(ii) Sowing	4 tractor-hrs	70/hr	280.00
3. Fertilizers and their application			
(i) Urea	261 kg	4.6/kg	1200.00
(ii) Single superphosphate	375 kg	3.2/kg	1200.00
(iii) Muriate of potash	67 kg	4.2/kg	281.00
(iv) Fertilizer application	3 man-days	65/man-day	195.00
4. Gap filling and thinning	4 man-days	65/man-day	260.00
5. Irrigation and cost of application	5 times 5 man-days	200/irrigation/ha 65/man-day	1000.00 325.00
6. Harvesting, threshing and cleaning	18 man-days	65/man-day	1170.00
7. Land rent	6 months	3000/ha/yr	1500.00
Grand total			Rs.9601.00

Prevailing prices of produce (HD 2285)

Grain: Rs. 6200/t

Straw: Rs. 400/t

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