

**EVALUATION OF PINOXADEN TO MANAGE WEEDS
IN WHEAT UNDER MID HILL CONDITIONS OF
HIMACHAL PRADESH**

THESIS

By

**PAWAN KATARA
(A-2010-30-17)**

Submitted to



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of

**MASTER OF SCIENCE IN AGRICULTURE
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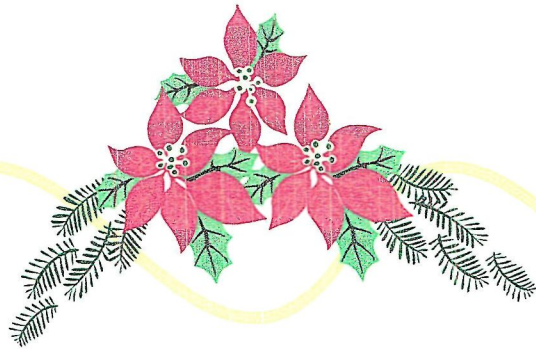
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CERTIFICATE – I

This is to certify that the thesis entitled “**Evaluation of pinoxaden to manage weeds in wheat under mid hill conditions of Himachal Pradesh**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy, Forages and Grassland Management** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Pawan Katara (Admission No. A-2010-30-17)** son of **Shri Shyam Bihari Katara** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.


The assistance and help received during the course of this investigation have been duly acknowledged.

Place: Palampur
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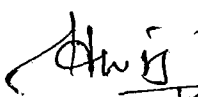
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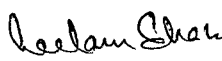
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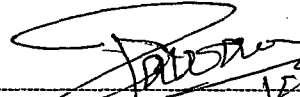
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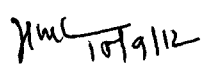
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Needless to mention, errors and omissions are mine.

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Pawan Katara
(Pawan Katara)

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1.	%	per cent
2.	&	and
3.	/	per
4.	a.i.	active ingredient
5.	°C	degree celcius
6.	cm	centimeter
7.	cv.	cultivar
8.	DAS	days after sowing
9.	day ⁻¹	per day
10.	<i>et al.</i>	et alii (and other)
11.	EC	emulsifiable concentrate
12.	<i>fb</i>	followed by
13.	Fig	figure
14.	g	gram
15.	g ⁻¹	per gram
16.	ha	hectare
17.	ha ⁻¹	per hectare
18.	<i>i.e.</i>	id est (that is)
19.	K	potassium
20.	kg	kilogram
21.	m	meter
22.	m ⁻²	per square meter

23.	ml	mililitre
24.	mm	millimeter
25.	N	nitrogen
26.	no.	number
27.	P	phosphorus
28.	p	page
29.	pp	pages
30.	q	quintal
31.	Rs.	rupees
32.	t	tonne
33.	WDG	water dispersible granule
34.	WP	wettable powder
35.	viz.	namely

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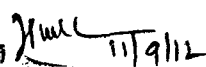
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Abstract

The field experiment was carried out at the experimental farm of Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur with fifteen weed control treatments viz. pinoxaden (50 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), carfentrazone-ethyl (20 g ha⁻¹) and 2, 4-D (500 g ha⁻¹) alone, pinoxaden (50 g ha⁻¹) with and before carfentrazone-ethyl (20 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹) and 2, 4-D (500 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), clodinafop fb 2, 4-D (60 fb 1000 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), weed free and weedy check were tested in a Randomized Block Design with three replications. Soil of the test site was silty clay loam in texture, acidic in reaction, low in available nitrogen, medium in available phosphorus and high in available potassium status. *Phalaris minor* and *Anagallis arvensis* were the major weeds constituting 60.8 and 21.4 per cent, respectively, of total weed flora at 90 DAS. The broad-leaf weeds (*Anagallis arvensis*, *Vicia sativa*, *Coronopus didymus*, *Stellaria media*, *Ranunculus arvensis* and *Oxalis latifolia*) as a whole constituted 27.9 per cent of total weed flora. Results of the study revealed that pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) and pinoxaden fb metsulfuron methyl (50 fb 4 g ha⁻¹) were comparable to weed free treatment and resulted in significantly lower population of *Phalaris minor*, *Avena ludoviciana*, *Lolium temulentum*, *Poa annua*, *Anagallis arvensis* and *Vicia sativa* and thereby significantly lower total weed dry weight. Tank mix application of pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) provided effective control of mixed weed flora and resulted in significantly higher grain yield, highest net returns (43542 Rs. ha⁻¹) and net returns per rupee invested (1.60). However it was statistically at par with pinoxaden (50 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden fb metsulfuron methyl (50 fb 4 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), clodinafop fb 2, 4-D (60 fb 1000 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden fb carfentrazone-ethyl (50 fb 20 g ha⁻¹), pinoxaden fb 2, 4-D (50 fb 500 g ha⁻¹) and weed free in increasing the grain yield of wheat.


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Introduction

1. INTRODUCTION

Human beings practically attain all their sustenance directly or indirectly from crop plants. Cereal crops provide about one-half of man's food calories and a major portion of his nutrient requirements. Wheat (*Triticum aestivum* L.) is foremost among cereals and indeed among all crops, as direct source of food for human beings. On the world basis, wheat ranks second after rice, providing protein and caloric requirements to one third of the population. It is the world's most widely cultivated food crop.

India is the second largest producer of wheat in the world after China. Wheat is the second most important crop after rice in India and occupies approximately 28.52 million hectares. The wheat production in India has touched a new height of 80.71 million tonnes in 2009-10 with an average productivity of 2852 kg ha⁻¹ (FAO 2010). India accounts for approximately 12% of global wheat production. On the other hand, India is also the second largest wheat consumer after China. In Himachal Pradesh, it occupies an area of 0.37 million hectares with a total production of 0.56 million tonnes and productivity of 1530 kg ha⁻¹ (Anonymous 2009-10). The present national average of 2.16 tonnes ha⁻¹ need to be raised to 3.5 tonnes ha⁻¹ to feed 1.25 billion population of the country by 2020 (Gautam 2001). It means we have to add within 10 years another 25 million tonnes of wheat, which is an opportunity as well as challenge. Irrespective of the area, it was evident that there exists a yield gap of 1.5-2.0 tonnes ha⁻¹ between what is being achieved and what can be achieved (Singh and Singh 2008).

Weeds may affect wheat production in many ways. Weeds compete with crop plants for light, water and minerals. Weeds may also inhibit crop growth through release of allelopathic chemicals that are toxic to wheat plants. Weeds or weed seeds contaminating harvested grain may reduce its quality. In addition, weeds may interfere with harvesting or raise the moisture content of the harvested grain, leading to damage from heat and pests in storage.

Introduction of high yielding dwarf varieties along with increased fertilizer use and improved irrigation facilities has virtually revolutionized wheat cultivation, but it has also led to complex problem of both grassy weeds (*Phalaris minor* and *Avena*

ludoviciana) and broad-leaf weeds (*Chenopodium album*, *Melilotus indica*, *Coronopus didymus*, *Anagallis arvensis* and *Vicia sativa*) [Balyan and Malik 1996]. Moderate infestation of *Phalaris minor* alone can cause 15-20 per cent reduction in grain yield of wheat (Walia and Gill 1985) while its heavy infestation (200 plants m⁻²) may result in complete crop failure or leading to premature harvest of wheat crop (Malik *et al.* 1995). Broad-leaf weeds in wheat may reduce the grain yield to the tune of 7-50 per cent depending upon their intensity (Kurchania *et al.* 2000). Therefore, competition by weeds is the major reason for the low productivity of wheat. Initial 30-45 days is the critical period of crop-weed competition in wheat crop. Looking into huge losses caused by weeds, it becomes essential to manage them effectively by all possible means.

Isoproturon is nationwide recommended herbicide in wheat: However, its continuous use particularly in the rice-wheat cropping system has led to the problem of resistant weeds. Continuous reliance on isoproturon after the evolution of resistance resulted in a heavy build-up of *Phalaris minor* and thereby caused huge yield losses. There were instances when wheat growers were forced to harvest their immature crop as fodder in absence of effective alternative herbicides (Malik and Singh 1995). Alternative recommended herbicides *viz.* clodinafop-propargyl, sulfosulfuron and fenoxaprop-p-ethyl, which are effective against resistant *Phalaris minor*, but these are costly and there is likely a risk of development of cross-resistance (Yadav *et al.* 2005). For broad-leaf weeds, 2, 4-D and metsulfuron methyl alone, or in combination with isoproturon are being widely used, but certain weed species such as *Rumex dentatus*, *Malva parviflora*, *Lathyrus aphaca* and *Fumaria parviflora* are not being effectively controlled. Combination of 2, 4-D or metsulfuron methyl with newly recommended herbicides like clodinafop and fenoxaprop also results into antagonism (Yadav *et al.* 2002). Pinoxaden is a new herbicide. At 40-60 g ha⁻¹, it is very effective against *Avena ludoviciana* and resistant *Phalaris minor* without any phytotoxicity, but it is not effective against broad-leaf weeds (Chhokar *et al.* 2008b; Singh and Punia 2007). 2, 4-D provides effective control of broad-leaf weeds but if used with Aryloxyphenoxypropionates, it antagonizes the effect of graminicides in wheat (Balyan *et al.* 1993).

Herbicides with differential selectivity can be applied sequentially, but it involves application in two rounds, resulting in enhancing the cost. Therefore, mixing two

different herbicides and applying them simultaneously widens the spectrum of weed-control, saves time and application cost and reduces impact of herbicides on environment (Green 1989).

Therefore, a need remains to evaluate new herbicides with different mode of action to tackle the ever increasing problem of complex weed flora. Keeping this in view, the present investigation entitled "*Evaluation of pinoxaden to manage weeds in wheat under mid hill conditions of Himachal Pradesh*" was conducted at the research farm of the Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur during *Rabi* 2010-11 with the following objectives:

- To study the relative efficacy of pinoxaden as tank mixture and sequential application with broad-leaf herbicides in controlling mixed weed flora and its effect on growth, development and yield of wheat and
- to work out the relative economics of different weed control treatments.

Review
of
Literature

2. REVIEW OF LITERATURE

In this chapter an attempt has been made to present a brief account of work pertaining to the problem under study carried out at different locations in India and abroad. The relevant work done has been reviewed under the following heads:

- 2.1 Major weed flora of wheat
- 2.2 Critical period of crop-weed competition
- 2.3 Losses caused by weeds in wheat
- 2.4 Phytotoxic effect of herbicides on wheat
- 2.5 Effect of herbicides
 - Effect of different herbicides alone in wheat
 - Effect of herbicide combinations in wheat
- 2.6 Economics
- 2.1 Major weed flora of wheat

Wheat fields are generally infested with both grassy and broad-leaf weeds. The intensity and composition of weed flora vary with soil type, environmental conditions like temperature, humidity, moisture availability, quality of irrigation water, cultural practices and crop rotations. In the crop-land ecosystem, a large variety of undesirable weeds reduce the crop productivity, as they compete with the crop for environmental resources (Bleasdale 1960).

Mishra *et al.* (2010) reported wild oat (*Avena sterilis* sp. *ludoviciana*), burclover (*Medicago hispida* Gaertn), littleseed canarygrass (*Phalaris minor* Retz.), common lambsquarter (*Chenopodium album* L.), common vetch (*Vicia sativa* L.) and lathyrus (*Lathyrus aphaca* L.), the most dominant weeds in wheat at Jabalpur.

Panwar *et al.* (1998) reported wild canary grass (*Phalaris minor*), yellow sweet clover (*Melilotus indica*), golden clock (*Rumex maritimus*), canada thistle (*Cirsium*

arvense) and lambsquarter (*Chenopodium album*), the most dominant weeds in wheat at Hisar. Similarly, Balyan (2001) from Hisar observed that *Phalaris minor*, *Avena ludoviciana*, *Chenopodium album*, *Melilotus indica*, *Anagallis arvensis*, *Lathyrus aphaca* and *Rumex* sp. were the major weeds in association with wheat crop. According to Sharma and Pahuja (2001), *Phalaris minor*, *Coronopus didymus*, *Chenopodium album*, *Melilotus indica*, *Anagallis arvensis* and *Cirsium arvense* were the major weeds in wheat at Hisar. Yadav *et al.* (2009) have also reported the association of *Phalaris minor*, *Coronopus didymus*, *Anagallis arvensis*, *Melilotus indica*, *Medicago denticulata*, *Rumex dentatus*, *Vicia sativa* and *Lathyrus aphaca* with wheat crop at Hisar. Panwar *et al.* (2000) reported the increasing problem of wild oat in south-western Haryana.

At Hisar, Balyan and Malik (1991) reported infestation of *Avena ludoviciana* in areas where rice-wheat rotation is not followed. Yadev *et al.* (2004) reported that the major weed flora in wheat were *Avena ludoviciana*, *Phalaris minor*, *Rumex retroflexus*, *Melilotus indica*, *Coronopus didymus* and *Chenopodium album* under Hisar conditions. From Hisar, Jat *et al.* (2005) reported that the dominant grassy weed flora in wheat comprised of *Phalaris minor* (29.7%) and *Avena ludoviciana* (40%), whereas the dominant broad-leaf weeds were *Lathyrus aphaca* L. (8.8%) and *Chenopodium album* L. (8.2%).

Shukla and Mishra (2006) reported the dominance of *Coronopus didymus*, *Melilotus indica*, *Chenopodium album* and *Phalaris minor* in wheat under Pantnagar conditions. Singh *et al.* (2005) reported a little infestation of broad-leaf weeds like *Medicago denticulata*, *Rumex dentatus*, *Melilotus indica* and *Anagallis arvensis* while *Phalaris minor* dominated the field at Hisar. Sinha and Singh (2005) reported almost similar weed flora in wheat at Varanasi.

Chopra *et al.* (2001) reported *Phalaris minor* the most pre-dominant weed among grasses, *Melilotus indica*, *Fumaria parviflora*, *Chenopodium album*, *Anagallis arvensis*, *Cirsium arvense*, *Rumex dentatus* among broad-leaf weeds and *Cyperus rotundus* among sedges at Baraut (U.P.).

In Pusa (Samastipur), the major weeds found growing in association with wheat crop were *Chenopodium album*, *Oxalis corniculata*, *Convolvulus arvensis*, *Lipia*

nudiflora, *Melilotus indica*, *Launea pinnatifida*, *Canabis sativa*, *Nicotiana plumbaginifolia* and *Spergula arvensis* among broad-leaf weeds and *Phalaris minor*, *Avena ludoviciana* and *Cynodon dactylon* among grassy weeds (Pandey *et al.* 2000). Thakur *et al.* (1995) reported that *Chenopodium album*, *Fumaria parviflora*, *Trigonella polycerata*, *Melilotus indica*, *Launea asplenifolia*, *Anagallis arvensis*, *Phyla nudiflora*, *Xanthium strumarium*, *Phalaris minor* and *Avena fatua* were the important weeds associated with wheat crop at Pusa.

Kurchania *et al.* (2000) reported *Medicago hispida*, *Melilotus alba*, *Trifolium flagiferum*, *Cichorium intybus*, *Chenopodium album*, *Indigofera linifolia*, *Anagallis arvensis*, *Phalaris minor*, *Vicia sativa*, *Sonchus arvensis* and *Cynodon dactylon*, the predominant weed species associated with wheat at Jabalpur.

From Jammu and Kashmir, Azad and Singh (1997) reported *Phalaris minor*, *Cynodon dactylon*, *Avena fatua* and *Poa annua* as the major grassy weeds and *Anagallis arvensis*, *Melilotus indica*, *Medicago denticulata*, *Chenopodium album*, *Lathyrus aphaca*, *Vicia sativa* and *Fumaria parviflora* as the major broad-leaf weeds in wheat.

Singh and Bhan (1998) reported that the most dominant weeds in wheat were *Chenopodium album*, *Chenopodium fistifolia*, *Cichorium intybus*, *Medicago hispida*, *Phalaris minor* and *Avena fatua* under Madhya Pradesh conditions. The population of grassy weeds like *Phalaris minor* and wild oat (*Avena ludoviciana*) have increased at a much faster rate replacing broad-leaf weeds in wheat fields at Hisar (Singh *et al.* 1995).

In Madhya Pradesh, the most dominant weed species in wheat were *Medicago denticulata*, *Anagallis arvensis*, *Chenopodium album*, *Cynodon dactylon*, *Cyperus rotundus*, *Digitaria adscendens*, *Cichorium intybus* (Agrawal and Jain 1998).

Sharma and Singh (2010) reported *Phalaris minor* (19.8%) among grasses, *Rumex dentatus* (34.3%), *Anagallis arvensis* (21.9%) and *Chenopodium album* (16.2%) among broad-leaf weeds and *Cyperus rotundus* (7.2%) among sedges, the major weeds invading wheat in Uttar Pradesh.

Brar and Walia (2009) reported the presence of *Trigonella polycerata*, *Lepidium sativa* and *Malva neglecta* alongwith other broad-leaf and grassy weeds under Punjab conditions.

At Udaipur, Jat *et al.* (2003) reported the dominance of *Chenopodium album* L., *Chenopodium murale* L., *Anagallis arvensis* L., *Convolvulus arvensis* L., *Coronopus didymus* L., *Melilotus indica* L. and *Phalaris minor* Retz. accounting for 28.5, 23.2, 7.9, 8.6, 3.0, 13.9 and 14.9%, respectively at 40 days after sowing.

In Kangra district of Himachal Pradesh, Angiras and Tripathi (1987) recorded higher frequency (80-100%) and density of *Alopecurus myosuroides*, *Anagallis arvensis*, *Polygonum alatum*, *Vicia sativa*, *Phalaris minor* and *Lolium temulentum* in irrigated wheat, whereas, under rainfed condition *Vicia sativa*, *Medicago denticulata* and *Avena fatua* were the dominating weeds. From Palampur, Saini and Singh (2001) reported that *Phalaris minor* Retz. and *Avena fatua* L. constituting 42.4 and 39.6% of the total weed population and were the major weed species infesting the wheat crop while *Lolium temulentum* L., *Alopecurus myosuroides* Huds., *Vicia sativa* L. and *Anagallis arvensis* L. showed their little infestation. Similarly, Kumar *et al.* (2011) reported that *Phalaris minor* (17.9%), *Avena ludoviciana* (18.9%), *Lolium temulentum* (39.0%), *Vicia sativa* (16.6%) and *Anagallis arvensis* (7.6%) were the major weeds growing in association with wheat crop at Palampur.

Thus, from the literature reviewed as above, it can be concluded that major weed species infesting wheat crop are *Phalaris minor*, *Avena ludoviciana*, *Alopecurus myosuroides*, *Lolium temulentum* and *Poa annua* among grasses and *Coronopus didymus*, *Anagallis arvensis*, *Melilotus indica*, *Medicago denticulata*, *Rumex dentatus*, *Vicia sativa*, *Fumaria parviflora*, *Chenopodium album* and *Lathyrus aphaca* among broad-leaf weeds. Grassy weeds are more dominant in wheat crop as compared to broad-leaf weeds.

2.2 Critical period of crop weed competition

Competition generally refers to the rivalry between the crop and weeds for a common demand which eventually runs short of supply and becomes a limiting factor (Zimdahl 1980). Critical period is the maximum period in which weeds can not be tolerated without affecting final crop yield, or the point after which, weed growth does not affect final yield (Dawson 1965). The yield loss of a crop depends on the length of crop-weed competition and stages at which the competition occurs.

Weeds are that part of non-crop vegetation which reduce quality and quantity of existing crop to such an extent that any net benefit of the weed plants themselves cannot compensate for their unfavorable effects on crops. The weeds compete with crop plants for space, moisture, light, carbon dioxide and take away a major share of native and applied plant nutrients that otherwise should have been utilized by the crop plants.

EI-Hamid *et al.* (1998) indicated that critical period of weed competition in wheat occurred during 4-6 weeks after sowing. At Anand (Gujrat), optimum yield of wheat was obtained with a weed free period between 30 to 45 days after sowing (Barevadia *et al.* 1993). Singh *et al.* (1985) reported that highest grain yield was obtained when plots were kept weed free till harvest followed by weed free until 60 days after sowing. From Baraut (U.P.), Chopra *et al.* (1999) reported that critical period of crop-weed competition was the first 32 to 40 DAS in wheat crop. Cruz *et al.* (2004) concluded that in wheat, the critical period of competition under high weed pressure was from 0 to 60 days after emergence while that under low pressure 15 to 70 days after emergence. Agostinetto *et al.* (2008) proposed that effective weed control measures should be taken between 12 and 24 days after emergence of wheat.

From Ambikapur (M.P.), Singh and Bajpai (1992) reported initial 40 days after sowing of wheat as critical period of weed competition, delaying the weeding beyond may suppress 1000-grain weight. In Bangladesh, Alam *et al.* (1994) reported 28 to 42 days after emergence as the critical period of weed competition in wheat. Rahman *et al.* (1990) in Bangladesh and Villasana *et al.* (2003) in Cuba reported 30 days after sowing as the critical period of competition from weeds in wheat. At Finta in Sudan, Mohamed (1997) concluded that the critical period was 8 to 10 weeks after sowing while at Elbar it was between 4 and 8 weeks after sowing.

Thus, under the light of literature reviewed as above, it can be concluded that wheat crop requires a time span during its growth particularly at the initial stages where interference due to weeds should be least. This time span for wheat may vary from 0-60 days after sowing and depending upon intensity, composition, time of emergence and other environmental conditions. Control of weeds during this period may result in considerable increase in grain yield. Managing the weeds beyond this period does not affect the crop yield significantly.

2.3 Losses caused by weeds

Weeds are the major constraints in realizing optimum yield potential. The ultimate effect of weed infestation in crop field is the reduction in yield and quality of the produce. The magnitude of effect depends on weed species, their intensity, duration of infestation, stages of critical competition and other management factors. They may cause a drastic reduction in yield to a level of one-third to almost total failure of crop. It is well established that losses caused by weeds exceed the losses from any other category of agricultural pest like insects, disease and rodents. Unlike insect-pests and diseases, losses due to weeds do not show any clear visual symptom especially at the early stages of growth. Therefore, farmers divert their little attention towards the weed control practices. But now weeds have been considered important pests of crops as they lower yields, increase cost of production and impair the quality of produce in various ways.

At Pantnagar, Singh and Singh (2005) revealed that the mixed population of *Phalaris minor* and *Chenopodium album* caused 66% reduction in wheat grain yield in weedy plots, whereas, *Chenopodium album* alone caused 22% reduction in wheat yield. Grassy weeds, particularly the littleseed canary grass (*Phalaris minor*) and wild oat (*Avena ludoviciana*) are the most serious problem of wheat and barley under irrigated conditions of Hisar (Balyan *et al.* 1991). Zimadahl and EI-Brahli (1992) reported 30% yield reduction by weeds in cereals in USA. In Punjab, the grain yield loss in wheat caused by weeds varies between 10 to 52% depending upon the nature and intensity of weeds, duration of crop-weed competition, climate, agronomic practices and relative emergence pattern of weeds in relation to crop (Walia *et al.* 1990).

Walia and Gill (1985) reported that among grassy weeds, *Phalaris minor* was posing a serious threat to wheat cultivation. Even moderate infestation of *Phalaris minor* alone caused 15-20% reduction in grain yield of wheat. Bhaskar and Vyas (1988) reported the growth, number of grains and grain weight per plant of wheat were severely reduced due to infestation by *Chenopodium album*. At Ludhiana, Brar and Walia (1989) reported that depending upon the intensity of wild oat, reduction in grain yield of wheat was recorded to an extent of 15 to 50% under Punjab conditions. Kulshrestha and Parmar (1992) stated that weeds were responsible for causing significant losses in crop productivity and quality, losses caused by weeds (about 33%) were reported to be more

than insects and other pests. Estimates showed that weeds in India cause an annual loss of Rs. 1980 crores.

From Assam, Gogoi *et al.* (1993) reported that weeds competing with the wheat crop throughout the season caused 35% reduction in grain yield. The reduction in grain yield, owing to weed competition for initial 15, 30, 45 and 50 days was 3.5, 7.8, 14.2 and 21.0%, respectively compared with season long weed free treatment which could be attributed to progressive increase in dry matter accumulation by weeds with delay in time of removal.

Malik and Singh (1995) reported that a population of 2000 plants per square meter of *Phalaris minor* resulted in complete crop failure at farmer's fields in Haryana State. Diwivedi *et al.* (1996) stated that weeds compete with wheat for nutrients, soil moisture, sunlight and space. Depending upon nature and intensity of weed flora, 30 to 50% reduction in grain yield of wheat was quite common. At Jabalpur, Kurchania *et al.* (2000) found that the infestation of broad-leaf weeds in wheat crop may lead to the reduction of grain yield to the tune of 7-50% depending upon their density.

At Ludhiana, Walia *et al.* (2004) found that the presence of one plant per meter row length of *Rumex spinosus* reduced grain yield by 2.5%, whereas 2 and 3 plants per meter row length reduced grain yield by 6.1 and 20.1%, respectively in wheat. Wheat crop infested with weeds like *Avena ludoviciana*, *Phalaris minor*, *Chenopodium album*, *Melilotus indica* and *Coronopus didymus* throughout the growing season caused 44.6% reduction in grain yield under Haryana conditions (Punia *et al.* 2006). Jain *et al.* (2006) reported that mixed weed flora composed of *Avena ludoviciana* (73%), *Phalaris minor* (0.62%), *Medicago hispida* (23.15%), *Chenopodium album* (2.61%), *Vicia sativa* (0.14%) and *Lathyrus aphaca* (0.41%) caused 65% reduction in grain yield of wheat under Jabalpur (M.P) conditions.

At Hisar, Punia *et al.* (2005) reported that presence of weeds throughout the growing period reduced grain yield of wheat by 49%. However, under Pantnagar conditions 65.2% loss in wheat grain was reduced by controlling weeds (Singh *et al.* 2005b). At Karnal (Haryana), a wheat field infested with *Rumex dentatus*, *Anagallis arvensis*, *Melilotus indica*, *Medicago denticulata* and *Phalaris minor* had 29% lower yield than weed free plots (Singh *et al.* 2005a). Chopra and Chopra (2005) reported 70.0% yield reduction under uncontrolled weedy check compared to clodinafop +

carfentrazone under Karnal conditions. The reduced grain yield of wheat to the extent of 51.9 to 57.6% due to presence of mixed population of grassy (65%) and broad-leaf weeds (35%) throughout the crop season may be attributed to the production of significantly less number of spikes under Hisar conditions (Malik *et al.* 2005). Similarly, more than 68.8 per cent reduction in the grain yield of wheat was reported by Singh *et al.* (2004) due to presence of *Phalaris minor*, *Chenopodium album*, *Melilotus sp.*, *Medicago denticulata* etc. under Pantnagar conditions. Chopra *et al.* (2001) reported 37.8% reduction in wheat yield due to higher weed intensity under unchecked growth of weeds in weedy plots in Baraut (U.P.). In Pakistan, more than 39% reduction in grain yield of wheat was recorded under weedy check plots compared to plots where weeds were controlled by application of affinity (carfentrazone-ethyl ester) at 0.016 kg a.i. ha⁻¹ (Khan *et al.* 2004).

Thus, from the literature reviewed as above, it can be concluded that grassy weeds, particularly the littleseed canary grass (*Phalaris minor*) and wild oat (*Avena ludoviciana*) are the most serious problem of wheat and cause 30 to 60 per cent reduction in grain yield.

2.4 Phytotoxic effects of herbicides on wheat

From Hisar, Singh *et al.* (2008) reported that a mixture of pinoxaden and clodinafop produced no residual toxicity on the succeeding sensitive crop. However, phytotoxicity of mesosulfuron + iodosulfuron (21.6 g ha⁻¹) to wheat significantly checked plant growth and produced lower yield than 14.4 g ha⁻¹ application rate. Similarly, Dixit *et al.* (2011) reported that pinoxaden at 40 g ha⁻¹ significantly reduced weed count and biomass in wheat crop. Following crop tolerated the application of pinoxaden in the preceding wheat crop and observations on weed control and yield were comparable with untreated one, showing no residual effect on the succeeding crop.

Saini *et al.* (2010) reported that pinoxaden has no residual toxicity on any test crop. However, application of mesosulfuron + iodosulfuron showed residual toxicity on maize, bajra, sorghum and bottle guard under Punjab conditions. Yadav *et al.* (2009) also observed that pinoxaden 5 EC at 50 g ha⁻¹ was not phytotoxic to wheat and had no residual toxicity on succeeding rice crop under Hisar conditions. Chhokar *et al.* (2008b) from Karnal also reported that there was no toxicity to any of the 18 barley genotypes screened for their sensitivity to pinoxaden (30 and 60 g ha⁻¹). At Pantnagar, Singh *et al.*

(2003a) reported that mesosulfuron + iodosulfuron at 15 + 3 g ha⁻¹ applied in wheat had no residual effect on the succeeding crops of transplanted rice and urdbean. However, maize crop in succession was adversely affected due to this treatment.

In Hisar, Balyan (2001) observed that tank mixture of isoproturon + metsulfuron methyl 750 + 4 g ha⁻¹ proved highly phytotoxic to wheat. Yadav *et al.* (2006) observed that oxyfluorfen at 50-100 g ha⁻¹ mixed with isoproturon 750 and 1000 g ha⁻¹ increased weed control efficiency (WCE) by 4-17% but did not increase yield due to phytotoxicity in Haryana. Singh and Ali (2004) reported that metsulfuron-methyl at 4 g ha⁻¹ did not have residual effect on succeeding soybean crop at Kota.

Thus, under the light of literature reviewed as above, it can be concluded that pinoxaden 5 EC at 50 g ha⁻¹ is not phytotoxic to wheat and has no residual toxicity on succeeding rice crop but mesosulfuron + iodosulfuron at higher doses has phytotoxicity to wheat.

2.5 Effect of herbicides

In areas where labour constraints exist during its peak demand for different cultural operation and shifting to other economic activities, herbicide use is increasing. Due to industrialization in the state, small family norms, and increase in literacy, farmers put strict focus on herbicides. Under certain specific situations where weeds are very difficult to remove manually, the use of herbicides becomes essential or unavoidable.

2.5.1 Effect of herbicides alone in wheat

2.5.1.1 Effect of pinoxaden

This herbicide belongs to phenylpyrazolin group with inhibiting action on acetyl-CoA-carboxylase (ACCase). Hoffer *et al.* (2006) obtained good control of grassy weeds (*Apera spicaventi*, *Alopecurus myosuroides*, *Avena ludoviciana*, *Lolium sp.*, *Phalaris minor*, and *Setaria sp.*) with post-emergence application of pinoxaden at 30-60 g a.i. ha⁻¹. Although this is also an ACCase inhibitor, it is a “den” instead of a “fop” (fenoxaprop) or “dim” (tralkoxydim) and is effective on herbicide resistant biotypes. Axial 5 EC (pinoxaden) is a new herbicide for the selective post-emergence control of weeds in winter wheat, durum wheat and barley. The product is characterized by the low rate, the broad spectrum activity on grasses, flexibility, selectivity on wheat and barley and fast degradation in the soil. It is effective through foliar absorption on the most important

grasses. Axial is mixable with the majority of dicot products marketed. It is a selective grass killer with foliar action and has no residual herbicidal activity in soil (Campagna and Rueegg 2006).

A random seed collection survey of 150 populations of wild oat across the west Australian wheat-belt in 2005 to identify the frequency and distribution of wild oat resistance to the ACCase inhibitor herbicides, revealed that only 23% of populations to be fully susceptible to diclofop, 88% susceptible to tralkoxydim, while 97% of populations were susceptible to Axial (Rusch 2008). A subsequent study in 2007 examined the frequency of ACCase resistance in 96 wild oat populations collected from a 2006 random survey of north-central and north-eastern Victoria. Screening of the same 96 biotypes showed only 2% of wild oat populations to be resistant to Axial in Australia.

Rusch (2008) obtained 97% suppression of wild oats and 98-100% of grassy and broad-leaf weeds with post-emergence application of pinoxaden.

Under the agroclimatic condition of Karnal (Haryana), post-emergence application of pinoxaden 10 EC at ≥ 27.5 g ha⁻¹ was comparable to the recommended herbicides sulfosulfuron, clodinafop and fenoxaprop in controlling grassy weeds and increasing grain yield of wheat (Punia *et al.* 2006). Similarly, Chhokar *et al.* (2008b) obtained effective control of *Phalaris minor*, *Avena ludoviciana* and *Polypogon monspeliensis* and 68% higher wheat grain yield over control with post-emergence application of pinoxaden at 35 g ha⁻¹, but it was not effective against broad-leaf weeds.

Kaur *et al.* (2007) observed that post-emergence application of pinoxaden (40 g ha⁻¹) provided complete control of isoproturon resistance *Phalaris minor* at Ludhiana. Yadav *et al.* (2009) reported that pinoxaden 5 EC 40 g ha⁻¹ + adjuvant 2000 ml ha⁻¹ and pinoxaden 5 EC (with built in adjuvant) 50 g ha⁻¹ reduced the dry weight of *Phalaris minor* to the extent of 92-99 and 82-98%, respectively at Karnal. Gowacki *et al.* (2007) also reported that when pinoxaden applied singly provided a very good control of *Avena fatua* and *Apera spicaventi* in winter cereals. In Italy, Frabboni and Russo (2008) obtained excellent control of *Phalaris paradoxa* and *Avena ludoviciana* with pinoxaden alone.

In preliminary studies under AICRP on weed control at Palampur, it was observed that pinoxaden 40 g ha⁻¹ behaving statistically alike with weed free resulted in

significantly lower count of *Phalaris minor*, *Avena ludoviciana* and *Lolium temulentum* (Anonymous 2009).

2.5.1.2 Effect of 2, 4-D

Chemical weed control in wheat and barley got a spurt with the introduction of phenoxy herbicides such as 2, 4-D during the Second World War. 2, 4-D has been found effective against broad-leaf weeds (Singh and Sharma 1984). 2, 4-D has been recommended widely for broad-leaf weed control in barley and wheat (Gulati *et al.* 1981). This herbicide belongs to phenoxyalkanoic acid group. It is a synthetic growth substance which exhibits auxin like properties. At lower doses it kills the weed slowly due to aberrant growth (Hanson and Slife 1969).

Singh and Malik (1994) reported that 2, 4-D sodium salt at 0.75 kg a.i. ha⁻¹ provided more than 90% control of *Chenopodium album*, whereas, the control of *Lathyrus aphaca* was only 20 to 68%. 2, 4-D sodium salt at 500 g ha⁻¹ could also provide significant reduction in the population and dry weight of *Lathyrus aphaca*. Pandey and Singh (1994) reported that application of 2, 4-D at 0.6 kg a.i. ha⁻¹ in wheat crop reduced population of *Melilotus indica*, *Chenopodium album* and *Anagallis arvensis* by 50, 100 and 100%, respectively. Nanda and Patro (1996) found that application of 2, 4-D Na salt at 1.5 kg a.i. ha⁻¹ significantly reduced the weed population and dry matter at 90 DAS. Consequently, the wheat yield increased from 15.8 q ha⁻¹ (control) to 18.5 q ha⁻¹ through 2, 4-D application. Agrawal and Jain (1998) found that application of 2, 4-D Na salt (0.5 kg ha⁻¹) as post-emergence was effective in controlling *Medicago denticulata*, *Chenopodium album*, *Digitaria adscendens* and total weed population compared to weedy check but failed to control *Cynodon dactylon*, *Cyperus rotundus* and *Cichorium intybus*. They also recorded significantly higher wheat grain yield (29.5 q ha⁻¹) compared to weedy check (20.5 q ha⁻¹). Application of 2, 4-DEE (0.5 kg ha⁻¹) and 2, 4-D Na salt (0.5 kg ha⁻¹) at 30 DAS resulted in significant control of *Medicago hispida*, *Melilotus alba*, *Trifolium flagiferum*, *Cichorium intybus*, *Chenopodium album*, *Anagallis arvensis* and *Vicia sativa* (46, 63, 32, 59, 98, 54 and 78% over weedy check, respectively) at 15 days after spraying but failed to control *Indigofera linifolia* (Kurchania *et al.* 2000). Sardana *et al.* (2001) found that post-emergence application of 2, 4-D at 0.5 kg ha⁻¹ significantly reduced population and dry matter of broad-leaf weeds and registered 58.6%

weed control efficiency at 60 DAS. Application of 2, 4-D at 500 g ha⁻¹ effectively controlled the broad-leaf weeds *i.e.* *Chenopodium album*, *Melilotus indica* and *Rumex retroflexus* in wheat (Bharat and Kachroo 2007).

2.5.1.3 Effect of metsulfuron methyl

This herbicide belongs to triazinylsulfonyleureas group. It inhibits acetolactate synthase (acetohydroxyacid synthase), the first enzyme in the synthetic pathways for valine, leucine and isoleucine amino acid. Metsulfuron methyl is applied as post-emergence at 30-35 DAS at 4-8 g ha⁻¹. It could be a good substitute of 2, 4-D. Since, it induces ear malformation in some varieties of wheat like Kundan.

From New Delhi, Yaduraju and Das (2002) reported that metsulfuron-methyl at 4 g ha⁻¹ gave excellent control of broad-leaf weeds especially *Cirsium arvense* L., a perennial weed in wheat. From West Bengal, Bhattacharya *et al.* (2006) reported that pre-emergence application of metsulfuron-methyl 20WP at 2.0 g ha⁻¹ was as good as hand weeding twice (20 and 40 DAS) in reducing the weed population and increasing grain yield of wheat. Whereas, in New Delhi, Paul *et al.* (2008) obtained 94.8-100.0% control of broad-leaf weeds and 21.3-21.7% higher grain yield of wheat over weedy check with the pre-emergence application of metsulfuron-methyl at 8 g ha⁻¹.

Sharma and Thakur (2002) at Bajaura (H.P.) reported that metsulfuron methyl at 4 and 5 g ha⁻¹ gave good control of *Veronica persica* in comparison to grasses and other broad-leaf weeds. Kurchania *et al.* (2000) reported that metsulfuron-methyl at 2 and 4 g ha⁻¹ was effective in controlling *Chenopodium album*, *Anagallis arvensis*, *Melilotus alba*, *Trifolium flagiferum*, *Medicago hispida*, *Vicia sativa* and *Cichorium intybus* but not against *Phalaris minor* at Jabalpur. They obtained higher grain yield of wheat with the application of metsulfuron-methyl at 4 g ha⁻¹ + 2, 4-D at 500 g ha⁻¹ (5038 kg ha⁻¹) or metsulfuron-methyl at 4 g ha⁻¹ + 2, 4-D at 250 g ha⁻¹ (4825 kg ha⁻¹) as against 3881 kg ha⁻¹ under weedy control.

Singh *et al.* (2002) at Pantnagar revealed that weed control efficiency of metsulfuron-methyl at 4.0 g ha⁻¹ applied alone was similar to metsulfuron-methyl at 2 g ha⁻¹ applied with surfactant. Singh and Ali (2004) also reported that metsulfuron-methyl at 4 g ha⁻¹ was most effective in controlling broad-leaf weeds and proved better than 2, 4-D at Kota. Chopra *et al.* (2008) reported that metsulfuron-methyl alone at 4 and 8 g

ha⁻¹ was found superior to 2, 4-D at 400 g ha⁻¹ and carfentrazone-ethyl at 10 g ha⁻¹ for dry weight of weeds and weed control efficiency at Baraut (U.P.). Sharma and Pahuja (2001) revealed that metsulfuron-methyl at 4 g ha⁻¹ was effective only against broad-leaf weeds at Hisar.

2.5.1.4 Effect of isoproturon

The herbicide belongs to phenylureas group with inhibiting action of photosynthesis at photosystem II. Isoproturon at 0.75 – 1.0 kg ha⁻¹ is applied as post-emergence at 28-30 days after sowing and after first irrigation at crown root initiation stage of wheat. Several herbicides have been found effective and among them isoproturon is being used for last 3-4 decades for controlling weeds especially grasses in wheat (Mishra *et al.* 2005).

From Baraut (U.P.), Chopra *et al.* (2001) reported lowest competition due to weeds in wheat in plots treated with 0.75 kg ha⁻¹ isoproturon. It also showed highest weed control efficiency against *Phalaris minor*. Similar results were also reported by Sharma and Pahuja (2001) with 1.0 kg isoproturon at Hisar. Whereas, isoproturon applied alone at 0.75 kg could not control wild oats at Hisar (Panwar *et al.* 2000). Kushwaha and Singh (2000) from Uttar Pradesh reported that pre-emergence application of isoproturon either at 0.52 or at 0.75 kg ha⁻¹ though reduced dry weight and count of both grassy as well as non-grassy weeds, but was not so effective against all broad-leaf weeds. Sharma (1991) reported that isoproturon at 1.50 kg ha⁻¹ as post-emergence application was the most effective herbicide treatment in controlling grassy weeds in wheat. Thakur and Singh (1988) reported that isoproturon at 1.25 kg ha⁻¹ gave effective control of weeds when applied as post-emergence at 2-3 leaf stage of weeds. In silty clay loam soils of Palampur, Saini and Angiras (1991) obtained better control of weeds (*Lolium temulentum*, *Phalaris minor*, *Vicia sativa* and *Avena fatua*) with isoproturon 1.5 kg ha⁻¹ when applied as pre-emergence and seedling stages of the wheat crop than at the maximum tillering stage.

From Hisar, Singh *et al.* (1999) reported that isoproturon (1.0 kg ha⁻¹) provided satisfactory control of *Chenopodium album* and *Phalaris minor*, but failed to control *Avena ludoviciana*, *Lathyrus aphaca* and *Vicia sativa*. In Madhya Pradesh, Dixit and Bhan (1998) observed that isoproturon at 0.50, 0.75 and 1.00 kg ha⁻¹ applied just before

irrigation provided better weed control and higher wheat yields, as compared to its application at 30 DAS. At Raipur, pre-emergence application of isoproturon at 1.25 kg ha⁻¹ was more effective than its post-emergence application (1.0 kg ha⁻¹) in reducing the dry weight production of *Phalaris minor* and increasing weed control efficiency (Singh and Kolhe 1998). Post-emergence application of isoproturon at 500 g ha⁻¹ significantly reduced weed density and dry weight (*Avena fatua*, *Chenopodium album*, *Fumaria parviflora* and *Cyperus rotundus*) and increased grain yield of wheat under Pakistan conditions (Sharif *et al.* 2005).

From Hisar, Malik *et al.* (1988) reported that isoproturon at 0.75 or 1.0 kg ha⁻¹ was effective against *Phalaris minor* and *Chenopodium album* but not against wild oat and other broad-leaf weeds. From Jammu and Kashmir, Azad and Singh (1997) reported that pre and post-emergence application of isoproturon at 0.75 kg ha⁻¹ provided 36.62 and 44.73% higher grain yield than weedy check, respectively. Post-emergence application of isoproturon was more effective than its pre-emergence application. From Jabalpur, Mishra (2006) reported that isoproturon at 1000 g ha⁻¹ did not cause significant reduction in the population and dry matter of wild oat, but significantly reduce the problem of broad-leaf weeds.

2.5.1.5 Effect of carfentrazone-ethyl

This herbicide belongs to phenyl triazolinones group. It inhibits amino acid production by inhibiting acetolactate synthase. Carfentrazone-ethyl at 20-40 g ha⁻¹ is applied as post-emergence (30-35 DAS). It could be a good substitute of 2, 4-D.

At Pantnagar Singh *et al.* (2004) obtained better control of *Chenopodium album*, *Melilotus alba*, *Lathyrus aphaca*, *Medicago denticulata* and *Rumex acetosella* with carfentrazone-ethyl at 20 g ha⁻¹. They found that carfentrazone-ethyl was comparable with metsulfuron-methyl but better than 2, 4-D. From Hisar, Punia *et al.* (2006) reported that post-emergence application of carfentrazone-ethyl at 20 g ha⁻¹ provided 92-100% control of all broad-leaf weeds including hard to controlling weeds like *Malva parviflora* and *Convolvulus arvensis* in wheat.

The post-emergence application of carfentrazone-ethyl at 20 and 25 g ha⁻¹ controlled broad-leaf weeds in wheat very effectively and produced grain yield at par with recommended 2, 4-D at 0.5 kg ha⁻¹ and increased wheat grain yield by 57.9% compared to weedy check at Ludhiana (Walia and Singh 2007).

2.5.1.6 Effect of clodinafop-propargyl

This herbicide belongs to aryloxyphenoxypropionates group. Clodinafop-propargyl is absorbed by the leaves and rapidly translocated to the growing points of leaves and stems. It interferes with the production of fatty acids by inhibition of acetyl CoA carboxylase which is needed for plant growth in susceptible grassy weeds. Clodinafop-propargyl is applied at 40-60 g ha⁻¹ as post-emergence at 30-35 DAS.

Malik *et al.* (2000) found clodinafop 60 g ha⁻¹ very effective against grassy weeds particularly *Avena ludoviciana* in wheat. Singh *et al.* (2005) found that clodinafop at 60 g ha⁻¹ significantly reduced the density of *Phalaris minor* and increased number of spikes and grain yield of wheat at Karnal. Dhawan *et al.* (2009) observed that clodinafop at 60 g ha⁻¹ increased the wheat yield by 35-50 per cent over weedy check during the first year of application and thereafter, with continued application of this herbicide, the increase in yield remained 17-35 per cent over weedy check due to the evaluation of cross resistance to this herbicide in *Phalaris minor* under Hisar conditions.

At Ludhiana, Walia *et al.* (2003) found that clodinafop at recommended level effectively controlled *Phalaris minor* and increased grain yield of wheat as compared to weedy check. Similarly, Chahal *et al.* (2003) at Ludhiana found that the application of clodinafop (60 g ha⁻¹) reduced the population and dry matter accumulation of *Phalaris minor* by 92.5 and 90.6%, respectively and hence resulted in 53.9% higher grain yield over weedy check. Jat *et al.* (2007) at Hisar reported that clodinafop at 60 g ha⁻¹ significantly reduced the population of *Phalaris minor* and *Avena ludoviciana* compared to weedy check. At Hisar, Malik *et al.* (2004) observed that with the increase in the dose of clodinafop from 40 to 50 or 60 g ha⁻¹, there was a gradual decline in the population and dry matter accumulation of grassy weeds.

Saini and Singh (2001) reported that clodinafop-propargyl 0.15 kg ha⁻¹ produced significantly lower weed dry weight and higher number of effective tillers, grains per spike and 1000-grain weight and hence grain yield at Palampur. Angiras *et al.* (2008) reported that clodinafop 75 g ha⁻¹ at 35 days after sowing effectively controlled *Avena ludoviciana* and *Phalaris minor* and resulted in significantly higher wheat grain yield.

2.5.1.7 Effect of mesosulfuron and iodosulfuron

These herbicides belong to pyrimidinylsulfonylureas and triazinylsulfonylureas group, respectively. These chemicals work by inhibiting the enzyme acetolactate synthase (ALS), which leads to depletion of key amino acids that are necessary for protein synthesis and plant growth. Mesosulfuron and iodosulfuron are applied at 13 and 18 g ha⁻¹ as post-emergence (30-35 DAS). In Poland, Adamczewski *et al.* (2000) obtained 90-100% weed control and significantly higher grain yield of winter cereals with iodosulfuron. Singh *et al.* (2003b) reported that alone application of mesosulfuron at 18.75 g ha⁻¹ was at par with sulfosulfuron at 25 g ha⁻¹ in reducing the density and dry weight of weeds under Haryana conditions.

Thus, from the literature reviewed above about alone application of herbicides, it can be concluded that application of pinoxaden and clodinafop provided excellent control of grassy weed *viz. Phalaris minor, Avena ludoviciana, Lolium temulentum* and *Poa annua*. Metsulfuron methyl and carfentrazone-ethyl provided excellent control of broad-leaf weeds *viz. Vicia sativa, Rumex dentatus, Chenopodium album, Anagallis arvensis* and *Convolvulus arvensis* and resulted in significantly higher grain yield.

2.5.2 Effect of herbicidal combination in wheat

The spectrum of weed flora is changing in such a way that many types of weeds infest wheat crop together. No single herbicide will be able to control all types of weeds without crop injury because of higher dose requirements for increasing the spectrum of weed kill. Some of the problematic weeds like *Cirsium arvense* and *Convolvulus arvensis* are not controlled by grass killing herbicides and continuous use of isoproturon has increased the intensity of *Anagallis arvensis* in the treated fields at Hisar (Malik and Singh 1993). Such problem of complex weed flora can only be tackled by combining grass killing herbicides with broad-leaf weed killers. Their use thereby, reducing the cost of weed management, arresting weed shifts, preventing herbicide resistance in weeds and facilitating improvement in overall weed management (Rao 1993). From Hisar, Chhokar and Malik (2002) reported that isoproturon resistance was not detected where crops and herbicides were rotated.

Post-emergence application of pinoxaden at 40-50 g ha⁻¹ fb metsulfuron significantly reduced the population and dry matter of weeds and increased the grain yield of barley and wheat (Kumar *et al.* 2010). Gowacki *et al.* (2007) reported that when pinoxaden applied in combination with other herbicides provided a very good control of *Avena fatua* and *Apera spicaventi* in winter cereals. In Italy, Frabboni and Russo (2008) obtained excellent control of *Phalaris paradoxa* and *Avena ludoviciana* with pinoxaden in combination with clodinafop.

Singh and Singh (2005) at Pantnagar reported that clodinafop-propargyl was compatible with metsulfuron-methyl and carfentrazone-ethyl as tank mixture with respect to control of *Phalaris minor* and *Chenopodium album* in wheat. Chopra and Chopra (2005) revealed that tank mixture of clodinafop (60 g ha⁻¹) with carfentrazone-ethyl (20 g ha⁻¹) controlled both grassy and broad-leaf weeds resulting in 88-90% weed control efficiency and significantly increased grain yield of wheat over sole application of clodinafop. At Ludhiana, Brar and Walia (2007) observed that post-emergence application of clodinafop at 60 g ha⁻¹ fb 2, 4-D at 500 g ha⁻¹ and mesosulfuron + iodosulfuron at 12 g ha⁻¹ significantly reduce the dry matter accumulation by all weeds and hence significantly reduce uptake of N, P and K by both *Phalaris minor* and broad-leaf weeds.

Mishra *et al.* (2010) reported that application of clodinafop at 60 g ha⁻¹ fb 2, 4-D ethyl ester at 500 g ha⁻¹ effectively controlled both grassy and broad-leaf weeds and produced 77.8% higher grain yield than that of isoproturon (1.0 kg ha⁻¹) + 2, 4-D (0.5 kg ha⁻¹) at Jabalpur. Punia *et al.* (2006) at Hisar observed that sequential application of 2, 4-D one week after spray of clodinafop-propargyl did not reduce efficacy of these herbicides and gave grain yield of wheat at par with weed free. Application of 2, 4-D and metsulfuron-methyl as tank mixture or one week before application of clodinafop reduced the efficacy of these herbicides against *Avena ludoviciana* and *Phalaris minor* (Punia *et al.* 2006; Jat *et al.* 2007). Jat *et al.* (2005) reported that application of clodinafop at 60 g ha⁻¹ fb metsulfuron at 4 g ha⁻¹ (7 DAS) effectively controlled the complex weed flora and produced grain yield of wheat equal to weed free treatment.

Panwar *et al.* (1998) at Hisar revealed that the application of 2, 4-D + isoproturon at 500 + 750 g ha⁻¹ at 5 week after sowing increased the weed control efficiency and

hence yield of wheat. Chauhan *et al.* (1999) reported that tank mixture of isoproturon + 2, 4-D at 0.5 + 0.25 kg ha⁻¹ after first irrigation provided drastic reduction in weed dry weight which was comparable to one hand weeding. From Hisar, Panwar *et al.* (1995a) reported that isoproturon + 2, 4-D at 1.2 + 1.3 kg ha⁻¹ gave good control of *Phalaris minor*, *Rumex maritimus*, *Melilotus indica*, *Chenopodium album* and *Avena ludoviciana* up to 90 DAS. From Pusa (Bihar), Pandey *et al.* (2001) reported that the mixture of isoproturon and 2, 4-D at 400 + 400 g ha⁻¹ significantly reduced weed population, dry biomass and nutrient removal by weeds and significantly increased nutrient uptake by crop over weedy check.

Kanojia and Nepalia (2004) from Udaipur (Rajasthan), reported that application of 2, 4-D + isoproturon (0.40 + 0.75 kg ha⁻¹) resulted in significant reduction in total weed density and dry matter at 40 and 80 DAS. Panwar *et al.* (1995b) found that isoproturon + 2, 4-D at 1.20 + 0.30 kg ha⁻¹ gave good control of mixed weed flora (87-95%). The highest grain yield of wheat was achieved with 0.75 kg isoproturon sprayed 20 days after sowing (Balyan *et al.* 1994). Khokhar and Nepalia (2010) reported that overall weed density and dry matter production at different stages of crop growth were minimized by isoproturon + 2, 4-D at 500 + 500 g ha⁻¹ and uptake of N, P and K by wheat crop was significantly higher in treated plots as compared to weedy check under Rajasthan conditions.

Under the agro-climatic condition of Gonbad, Shahroud and Dezfoul (Iran), clodinafop-propargyl acted better when tank mixed with broad-leaf herbicides but dual purpose herbicide iodosulfuron-methyl-sodium plus mesosulfuron-methyl at 21 g a.i. ha⁻¹ was also a good option in controlling weeds (Baghestani *et al.* 2008). Similarly, Rapparini and Geminiani (2007) from Italy found mesosulfuron + iodosulfuron (300 g ha⁻¹) quite effective against *Lolium multiflorum*, *Phalaris paradoxa* and *Avena ludoviciana*.

From Uttaranchal, Singh *et al.* (2003a) reported that a ready mix formulation of mesosulfuron + iodosulfuron at 15+3 g ha⁻¹ was highly effective in controlling *Phalaris minor*, *Chenopodium album*, *Melilotus indica* and *Medicago denticulata* in wheat cv. UP 2425 and produced grain yield similar to weed-free conditions. Similarly, from Haryana, Singh *et al.* (2003b) reported that ready mixture of mesosulfuron + iodosulfuron at 15+3

g ha⁻¹ provided effective control of weeds and produced effective tillers and grain yield similar to the plots kept weed-free for the whole season. Walia *et al.* (2005) reported that mesosulfuron + iodosulfuron at 12 or 15 g ha⁻¹ provided effective control of *Phalaris minor* and broad-leaf weeds, whereas clodinafop at 60 g ha⁻¹ controlled *Phalaris minor* only.

Brar *et al.* (2003) at Ludhiana observed that application of mesosulfuron + iodosulfuron at 12 and 15 g a.i. ha⁻¹ increased grain yield of wheat by 43.8 and 49.3%, respectively than control against 48.7% in clodinafop 60 g ha⁻¹. At Ludhiana, Kaur *et al.* (2007) also observed that all doses of mesosulfuron + iodosulfuron (12, 18, and 24 g ha⁻¹) were at par with each other in term of yield of wheat as the herbicides gave an effective kill of weeds.

Balyan (2001) reported that tank mixture of isoproturon and metsulfuron 750 + 4 g ha⁻¹ provided satisfactory control of dominant weeds like *Avena ludoviciana*, *Phalaris minor*, *Chenopodium album*, *Melilotus indica*, *Anagallis arvensis* and *Lathyrus aphaca* at Hisar. Sharma and Pahuja (2001) revealed that the efficacy of tank mixture of metsulfuron methyl at 2 g ha⁻¹ and isoproturon at 500 g ha⁻¹ was very poor against both types of weeds. Kurchania *et al.* (2000) reported higher grain yield of wheat with the application of metsulfuron-methyl at 4 g ha⁻¹ + 2, 4-D at 500 g ha⁻¹ (5038 kg ha⁻¹) or metsulfuron-methyl at 4 g ha⁻¹ + 2, 4-D at 250 g ha⁻¹ (4825 kg ha⁻¹) as against 3881 kg ha⁻¹ under weedy control. From Pantnagar, Singh and Singh (2002) revealed that ready mix formulation of metsulfuron-methyl + isoproturon at 6.0 + 500 g ha⁻¹ and 2, 4-D + isoproturon at 500 + 1000 g ha⁻¹ significantly reduced the total density of weeds and their dry matter production. Sharma and Thakur (2002) reported that combination of metsulfuron methyl at 5 g ha⁻¹ with isoproturon at 0.75, 1.00 and 1.25 kg ha⁻¹ and combination of metsulfuron methyl at 4 g ha⁻¹ with isoproturon at 1.00 and 1.25 kg ha⁻¹, the most effective weed control treatments at Bajaura (H.P.).

Kumar *et al.* (2011) reported that the application of affinity (isoproturon + carfentrazone-ethyl) 1.55 kg ha⁻¹ at 45 days after sowing provided as effective control of weeds as at 2.0 and 2.5 kg ha⁻¹ at Palampur. From Peshawar (Pakistan), Khalil (2008) reported that post-emergence application of affinity 50 WDG (carfentrazone ethyl + isoproturon) at 16 g ha⁻¹ effectively reduced the population and biomass of weeds. Dixit

and Singh (2008) documented that the ready mix formulation of carfentrazone-ethyl + isoproturon at 15 + 1000 g ha⁻¹ effectively controlled weeds in wheat (>90% weed control efficiency) and recorded yield (6500 kg ha⁻¹) similar to weed free treatment in New Delhi.

Punia *et al.* (2004) reported that tank mix combination of 2, 4-D with clodinofofop was antagonistic resulting in poor control of grassy weeds and thereby lower yield of wheat.

Thus, from the literature reviewed above about combination of herbicides, it can be concluded that application of grassy herbicides in combination with broad-leaf herbicides provided excellent control of complex weed flora and no antagonism was observed in their simultaneous application as tank mixture.

2.6 Economics

Weeds should be controlled by least expensive available technology that does not interfere with other phases of crop production or other human activities. Any weed control measures should be used only when its results are expected to be more economically beneficial than without using any control measure (Moody 1993). Farmers compare time and cost of weed control and usually select management tactics having the lowest cost. Therefore, choice of weed control inputs depends not only on its efficacy but also on its cost (De-dutta and Foster 1977).

Marginal benefits cost ratio and net returns are the best way to assess the economic viability of a particular weed control treatment. However, Padmavati *et al.* (1995) reported highest seed yield and net returns with hand weeding twice (1910 kg and Rs. 9533 ha⁻¹, respectively). Kankal *et al.* (1999) also reported highest net profit and benefit: cost ratio by following mechanical weed control at Rahuri.

Singh and Singh (2004) reported highest grain yield of wheat (3980 kg ha⁻¹) with two hand weeding, but additional investment with two hand weeding decreased the net returns (Rs. 7480) over pendimethalin plus one hand weeding (Rs. 8063). From Pusa, Pandey *et al.* (2000) reported that the weed control through herbicides gave significantly higher benefit: cost ratio than hand weeding. Bharat and Kachroo, 2007 reported that isoproturon + 2, 4-D was the most economical among the all herbicidal treatments. From

Jabalpur, Mishra (2006) reported that application of clodinafop 60 g ha⁻¹ significantly increased the net returns over weedy check. Azad and Singh (1997) observed that net profit of Rs. 5797.93 and 6382.39 ha⁻¹ were obtained in pre and post-emergence sprays of isoproturon and these treatments on an average gave additional profit of Rs. 1753.91 and 2338.37 over hand-weeding, respectively under Jammu and Kashmir conditions.

Tiwari and Parihar (1997) reported that the herbicides application increased the net profit over the control (weedy check) and 1 hand-weeding at Madhya Pradesh. Chopra *et al.* (2008) recorded the lower monetary returns with sole application of 2, 4-D, carfentrazone-ethyl and metsulfuron methyl due to inability of these herbicides to control *Phalaris minor* under western Uttar Pradesh conditions. From Pusa, Sinha and Singh (2004) obtained maximum net returns from weed free plot, while benefit: cost ratio was obtained maximum with isoproturon at 0.5 kg ha⁻¹ with teepol 2%. In Pakistan, Nadeem *et al.* (2007) reported that all weed control practices gave higher net field benefit than weedy check.

Angiras *et al.* (2008) reported that clodinafop 75 g ha⁻¹ applied at 35 DAS resulted in significantly higher grain yield and net return over weedy check under Palampur conditions. Kumar *et al.* (2011) reported that application of isoproturon + carfentrazone-ethyl at 1.5 kg ha⁻¹ at 45 DAS resulted in highest additional yield over weedy check and thereby additional gross returns, net returns and net returns per rupee invested on weed control at Palampur.

Materials
and
Methods

3. MATERIALS AND METHODS

The field experiment was conducted at the research farm of Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur (H.P.) during *Rabi* 2010-11. The materials used and the methods employed during experimentation have been described in this chapter.

3.1 Details of the experimental site

3.1.1 Experimental site

The experimental farm was located at 32⁰6' N latitude, 76⁰3' E longitude and 1290 meters altitude. The site falls in the sub-temperate mid hill zone of Himachal Pradesh. The region is endowed with mild summers and cool winters.

3.1.2 Climate and weather conditions

Agro climatically the experimental site falls in sub temperate humid zone and represents mid hill zone of Himachal Pradesh. The location is characterized by severe winter and mild summer. Annual rainfall of the place in the recent past varied from 1500 to 2500 mm, of which 80% was received during June-September. Mean weekly weather parameters like maximum and minimum temperature, relative humidity, bright sunshine hours and rainfall pertaining to the cropping seasons (November 2010 to May 2011) recorded at the meteorological observatory of the Department have been given in Appendix-I and illustrated in Fig. 3.1.

During growing season (November to May) the weekly maximum and minimum temperature ranged between 12.0 to 33.5 °C and 2.4 to 20.9 °C, respectively. The crop experienced well distributed rainfall of 450 mm during growing season. The highest weekly rainfall of 108.8 mm was received during 7th meteorological week *i.e.* February. The mean weekly sunshine hours ranged from 2 to 10.5 hours during the growing season.

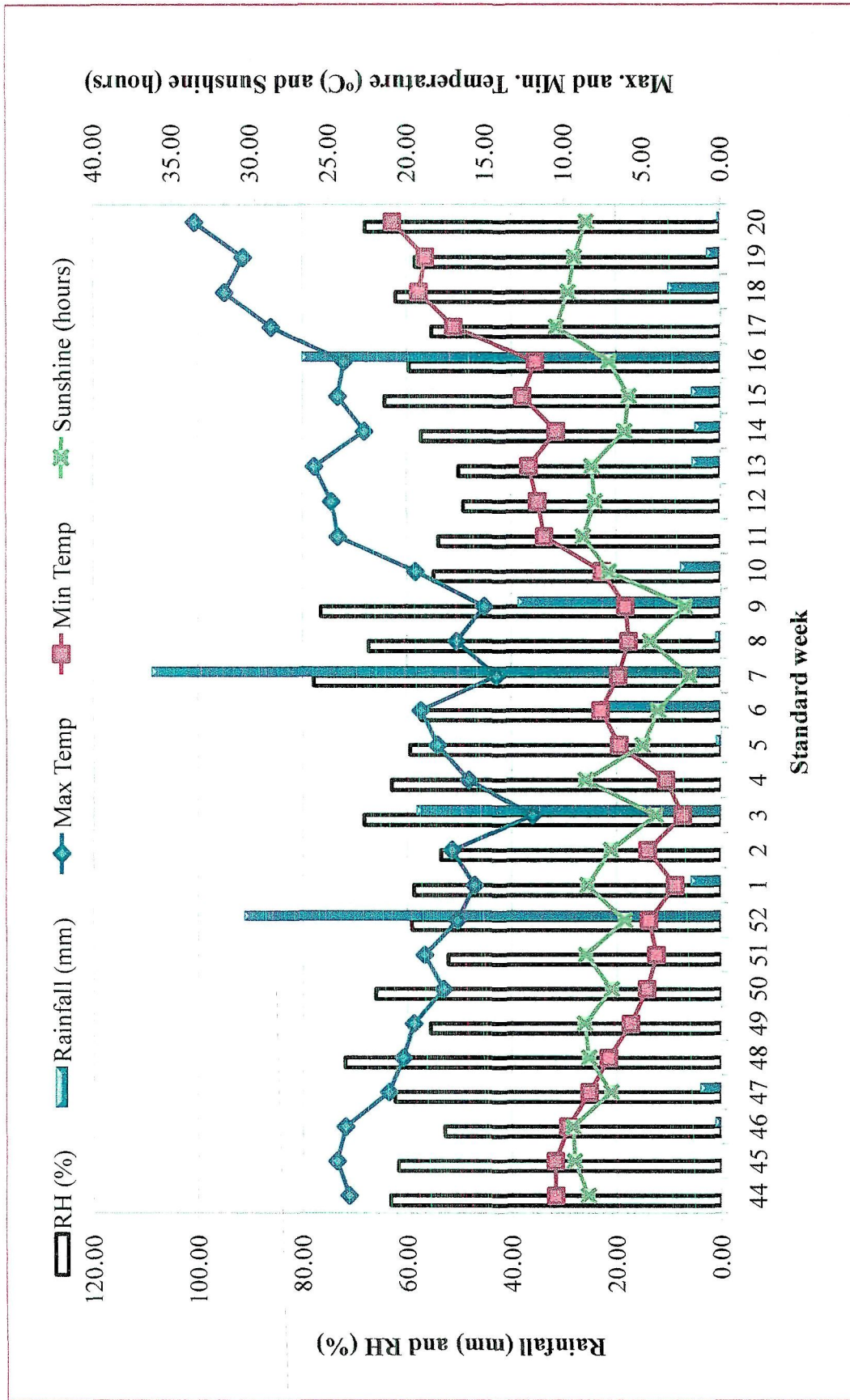


Fig.3.1 Mean weekly meteorological data for the period from November, 2010 to May, 2011 at Palampur

3.1.3 Soil characteristics

Composite soil samples from 0-15 cm depth were collected from the experimental field before the sowing of the crop. The soil samples were then air dried, ground, passed through 2 mm sieve and analyzed for various physico-chemical properties as per standard methods. The results of the analysis have been presented in Table 3.1.

Table 3.1 Physico-chemical properties of experimental soil (0-15 cm) before sowing

Particulars	Content in soil	Analytical method employed
A. Physical properties		
Sand (%)	20.3	
Silt (%)	43.4	International pipette method (Piper 1966)
Clay (%)	35.6	
Texture	Silty clay loam	
B. Chemical properties		
pH	6.1	1:2.5 soil water suspension (Jackson 1967)
Available Nitrogen (kg ha ⁻¹)	322.97	Alkaline permanganate method (Subbiah and Asija 1956)
Available Phosphorus (kg ha ⁻¹)	25.82	Olsen method (Olsen <i>et al.</i> 1954)
Available Potassium (kg ha ⁻¹)	276.39	Ammonium acetate extraction method (AOAC 1970)

Soil of experimental area was silty clay loam in texture, acidic in reaction, low in available nitrogen, medium in available phosphorus and high in available potassium status.

3.1.4 Cropping history

The experimental field was under the crop of pea in *Rabi* and maize in *Kharif* during the past three seasons. The crops were raised with the uniform application of fertilizers as per package of practices.

Table 3.2 Cropping history

Year and season	Crop
2009, <i>Kharif</i>	Maize
2009-10, <i>Rabi</i>	Pea
2010, <i>Kharif</i>	Maize
2010-11, <i>Rabi</i>	Present experiment (wheat)

3.2 Treatment details

The present experiment was conducted in randomized block design with three replications. Including weedy check and weed free, there were in all 15 treatments which involved seven herbicides. The detail of herbicides used have been appended in Appendix-II. The detail of treatments has been given here as below:

Treatments:

Sr. No.	Treatment	Dose (g ha ⁻¹)	Time of Application (DAS)
1.	Pinoxaden	50	28
2.	Metsulfuron methyl	4	28
3.	Pinoxaden + carfentrazone-ethyl	50 + 20	28
4.	Pinoxaden + metsulfuron methyl	50 + 4	28
5.	Pinoxaden + 2,4-D	50 + 500	28
6.	Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	28 & 35
7.	Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	28 & 35
8.	Pinoxaden <i>fb</i> 2,4-D	50 <i>fb</i> 500	28 & 35
9.	Carfentrazone-ethyl	20	28
10.	Mesosulfuron + iodosulfuron	13 + 5	25-30
11.	Isoproturon + 2,4-D	1250 + 500	25-30
12.	Clodinafop <i>fb</i> 2,4-D	60 <i>fb</i> 1000	35 & 37
13.	2,4-D	500	28
14.	Weed free	-	-
15.	Weedy check	-	-

Gross plot size	:	4.5 m X 2.8 m = 12.6 m ²
Net plot size	:	3.6 m X 1.8 m = 6.48 m ²
Design	:	RBD
Replications	:	Three
Total number of treatments	:	15
Total number of plots	:	45
Variety	:	HPW-155

3.3 Field operation

a. Preparation of field

The seed bed was prepared with the help of tractor driven disc plough and harrow after pre-sowing irrigation, when the field attained optimum soil moisture conditions. The experimental field was ploughed and harrowed twice. The clods were broken and *suhaga* was given to level the field properly so as to facilitate the layout and planting operation.

The layout of the experiment was carried out with the help of manual labours. Stones, stubbles and weeds were removed from the field. Field was divided into blocks equal to the number of replications. In each block 15 plots equal to the number of treatments of size 12.6 m² (4.5 m x 2.8 m) were prepared with bunds of 30 cm width.

b. Sowing

The seeds of wheat variety HPW- 155 were sown in furrows 22.5 cm apart using 100 kg ha⁻¹. The furrows were opened with the help of a hand plough. After putting 126 g seeds per plot, the furrows were then covered with the soil properly.

c. Fertilizer application

The crop was fertilized with 120 kg N, 60 kg P₂O₅ and 30 kg K₂O per hectare. Nitrogen, phosphorus and potassium were applied through urea (46% N), single super phosphate (16% P₂O₅) and muriate of potash (60% K₂O), respectively. One third N and whole P₂O₅ and K₂O were applied at the time of sowing. The remaining N was applied in two equal splits, first at maximum tillering and second at flower initiation stage.

d. Inter-culture and weed management

The hand weeding in weed free treatment was given at particular interval day after sowing. Herbicides as per treatments were applied with knapsack power sprayer using 750 liters water per hectare.

e. Harvesting

On maturity, the crop from net plots was harvested with the help of sickles. The produce was sun dried for one day.

3.4 Date of agronomic operation

The dates of various operations done during the period of experimentation are presented in Table 3.3.

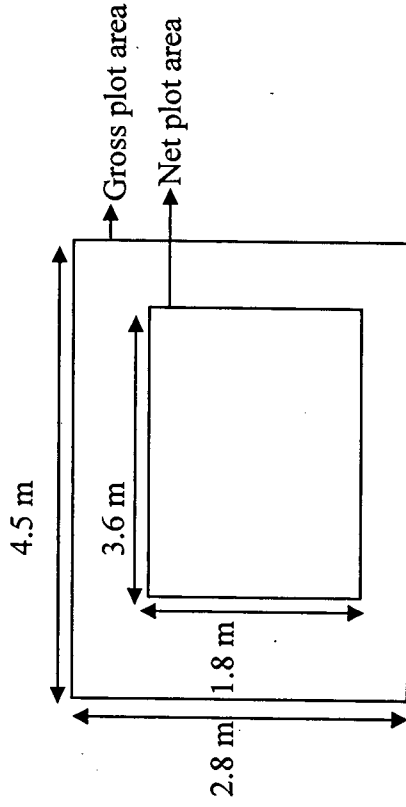
Table 3.3 Schedule of cultural and other operations performed

Sr. No.	Operation	Date
1.	Pre-sowing irrigation	25 October 2010
2.	Field preparation	3 November 2010
3.	Layout	3 November 2010
4.	Sowing	4 November 2010
5.	Basal application of fertilizers	4 November 2010
6.	Herbicide application	
	(a) I st application	1 December 2010
	(b) II nd application	8 December 2010
	(c) III rd application	10 December 2010
7.	Top dressing of urea (i)	29 December 2010
	(ii)	21 February 2011
8.	Hand weeding (as per treatments)	When weed emerged in plot, they were removed from weed free treatment
9.	Irrigation (i)	25 November 2010
	(ii)	18 December 2010
	(iii)	22 January 2011
	(iv)	8 March 2011
	(v)	10 April 2011
10.	Fungicide spray	24 March 2011
11.	Harvesting	15 May 2011
12.	Threshing	18 May 2011

3.5 Layout

As mentioned earlier there were 15 treatments which were replicated thrice. The treatments were allocated randomly to each plot using random number table. The layout plan of the experiment has been shown in Fig. 3.2.

Chadiar road														
R1														
T ₁₁	T ₁₀	T ₃	T ₆	T ₂	T ₁	T ₈	T ₁₅	T ₉	T ₄	T ₅	T ₁₂	T ₁₄	T ₁₃	T ₇
Irrigation channel														
R2														
T ₁₀	T ₁	T ₆	T ₉	T ₄	T ₁₅	T ₅	T ₈	T ₁₂	T ₁₄	T ₁₃	T ₃	T ₇	T ₂	T ₁₁
Irrigation channel														
R3														
T ₁₂	T ₄	T ₈	T ₁	T ₆	T ₁₀	T ₅	T ₁₅	T ₂	T ₇	T ₉	T ₁₃	T ₁₁	T ₃	T ₁₄



- T₁- Pinoxaden, T₂- Metsulfuron methyl, T₃- Pinoxaden + carfentrazone-ethyl,
T₄- Pinoxaden + metsulfuron methyl, T₅- Pinoxaden + 2, 4-D,
T₆- Pinoxaden *fb* carfentrazone-ethyl, T₇- Pinoxaden *fb* metsulfuron methyl,
T₈- Pinoxaden *fb* 2, 4-D, T₉- Carfentrazone-ethyl,
T₁₀- Mesosulfuron + iodosulfuron, T₁₁- Isoproturon + 2, 4-D,
T₁₂- Clodinafop *fb* 2, 4-D, T₁₃- 2, 4-D, T₁₄- Weed free, T₁₅- Weedy check

Fig. 3.2 Layout plan of experiment

3.6 Detailed observation recorded

The procedures followed for recording various observations on weeds and crop have been given in this section under following sub heads:

3.6.1 Weed studies

a. Species-wise weed count

In each plot, a 50 cm x 50 cm quadrat was placed randomly at two spots. The species-wise weed count was recorded at 60, 90, 120, 150 DAS and at harvest. The population so recorded was averaged and converted into number per square meter by multiplying the value with factor 4. The total weed count was obtained by summing up the count of different weed species.

b. Total weed dry matter accumulation

The sample of weeds were collected at monthly interval commencing from 60 DAS by throwing 50 cm x 50 cm quadrat at random in each plot. These samples were oven dried at a temperature of 70 °C till constant weight and total dry matter accumulation of weeds per square meter was recorded by multiplying it with factor 4.0.

c. Weed control efficiency (WCE) / index (WCI)

Weed control efficiency or weed control index was worked out based on weed population or weed dry weight as per the formula outlined by Mani *et al.* (1973) and Mishra and Tosh (1979), respectively.

$$\text{Weed Control Efficiency / index (\%)} = \frac{W_c - W_t}{W_c} \times 100$$

Where,

W_c - Weed population (no. m^{-2}) / weed dry weight ($g\ m^{-2}$) in control plot and

W_t - Weed population (no. m^{-2}) / weed dry weight ($g\ m^{-2}$) in treated plot.

d. Weed growth analysis

Weed growth rate (GR_w) and relative growth rate (RGR_w) of weeds was calculated by the formulae outlined by Watson (1962).

$$GR_w\ (g/m^2/day) = \frac{W_2 - W_1}{t_2 - t_1}$$

$$\text{RGRw (g/g/day)} = \frac{\text{Log}_e W_2 - \text{log}_e W_1}{t_2 - t_1}$$

Where, W_2 and W_1 are the total dry weight at times t_2 and t_1 , respectively

e. Weed index

It is a measure of the efficacy of a particular treatment when compared with a weed free treatment. It is expressed as percentage of yield potential under weed free. Higher weed index means greater loss due to weeds. Weed index was calculated by the formula outlined by Gill and Vijayakumar (1966).

$$\text{Weed index} = \frac{X-Y}{X} \times 100$$

X- Yield from weed free treatment

Y- Yield of particular treatment for which WI is to be worked out

3.6.2 Crop studies

A. Growth studies

a. Emergence count

As and when the emergence started, plant of wheat from one meter row length in each observational line were counted at alternate day till constant population was achieved. The final observation was recorded as emergence count per square meter by multiplying the mean of counted plants from the two observational lines with the factors 4.44.

b. Plant height

The plant height was recorded at tillering, earing and harvesting stages. Five plants were selected randomly from the net plot area and were tagged. Height of these tagged plants was recorded from the ground level up to top most leaf tip. The average of these plants was taken as a mean plant height in cm.

c. Number of tillers

Number of tillers per meter row length was counted at tillering, earing and harvesting and expressed as tillers per square meter by multiplying with factor 4.44.

d. Dry matter accumulation

The second row from both sides of each plot was taken as sampling row. In each sampling row, wheat plants from half meter row length were cut from ground level at monthly interval and oven dried at 70 °C till a constant weight was obtained. The total weight thus recorded was multiplied by the factor 4.44 to express dry weight as g m⁻².

e. Crop growth analysis

Crop growth rate (CGR) and relative growth rate (RGR) of wheat crops was calculated by the formulae outlined by Watson (1962).

$$\text{CGR (g/m}^2\text{/day)} = \frac{W_2 - W_1}{t_2 - t_1}$$

$$\text{RGR (g/g/day)} = \frac{\text{Log}_e W_2 - \text{log}_e W_1}{t_2 - t_1}$$

Where, W_2 and W_1 are the total dry weight at times t_2 and t_1 , respectively.

B. Developmental studies

a. Days to emergence

The emergence count was recorded from the sampling area daily from the date of first emergence of seeding till it was constant. The number of days taken to emergence was worked out from the date of sowing.

b. Days to 50 per cent earing

To observe the emergence of ear-heads, the plots were visited regularly after boot stage. When 50 per cent of shoots in the plot bore ears, the date was noted and days taken for earing were worked out from the sowing date.

c. Days to maturity

When plants turned golden yellow and the grains did not crush with nails, observations on days to maturity were recorded. The date on which grains attained sufficient hard stage was recorded and days taken for maturity were counted from the sowing date.

3.8 Yield attribute and Yield

a. No. of effective tillers per meter row length

The number of effective tillers per running meter from tagged area were counted at the time of harvesting and expressed as effective tillers per square meter by multiplying with factor 4.44.

b. Grains per spike

Five spikes were randomly selected from each plot and threshed. The grains were cleaned and counted, the mean of five spikes was given as grains per spike.

c. Test weight

Composite random samples from the produce of net plots were drawn and 1000-grains were counted by seed counter and weighed. This was recorded as test weight in grams.

d. Grain yield

The produce from each net plot was harvested and threshed after sun drying. The grains were cleaned and weighed after threshing. The weight of grains recorded was converted to kg per hectare by multiplying plot yield (kg) with factor 1543.21.

e. Straw yield

Total biological yield (grain + straw) from each net plot was recorded by weighing the sun dried harvested crop. The straw yield was worked out by subtracting the grain yield from biological yield. It was then converted to kg per hectare by multiplying the plot yield (kg) with factor 1543.21.

f. Harvest index

Harvest index was worked out by dividing the grain yield with biological yield.

3.9 Nutrient uptake by weeds and crop

Nutrient uptake by weeds was determined at maximum dry matter stage of weeds. Weeds at maximum dry matter stage, grain and straw samples of wheat at harvest were collected, dried in oven at 70 °C for 3-4 days, then ground and stored in paper bags for further analysis. The oven dried sample of weeds, wheat grain and straw were analyzed for N, P and K content using the method as outlined by Li (1966). Uptake of N, P and K by weeds, wheat grain and straw was obtained by multiplying their nutrient content with corresponding dry matter. Total uptake by crop was obtained by adding the uptake by grain and straw.

The detail of chemical analysis is given below:

Parameter	Method	Reference
Total Nitrogen	Modified Kjeldahl's Method	Jackson (1967)
Total Phosphorus	Vanadomolybdate phosphoric acid yellow colour method	Jackson (1967)
Total Potassium	Diacid digestion method	Black (1965)

3.10 Economic studies

In order to work out the most profitable treatment, the economics of each treatment was worked out on the basis of prevalent market prices of the inputs and output.

a. Cost of cultivation (Rs. ha⁻¹)

Cost of cultivation was calculated by adding all the costs involved in each operation or input. The computed cost of cultivation has been appended in Appendix-III-IV.

b. Gross returns (Rs. ha⁻¹)

The yield of the crop was converted into gross returns in rupees based on the prevailing market prices of seed as given in Appendix-V to obtain treatment-wise gross returns.

c. Net returns (Rs. ha⁻¹)

The treatment-wise net returns were obtained by subtracting the cost of cultivation from gross returns.

d. Net returns per rupee invested

Net returns per rupee invested were obtained by dividing net returns with the treatment-wise cost of cultivation as follow:

$$\text{Net returns per rupee invested} = \frac{\text{Net returns from a treatment (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation of the treatment (Rs. ha}^{-1}\text{)}}$$

3.11 Statistical analysis

The data obtained were subjected to statistical analysis as per Gomez and Gomez (1984) and were tested at 5 per cent level of significance to interpret the treatment differences. The weed count and weed dry weight data were analyzed after subjecting the original data to square root transformation *i.e.* $\sqrt{(x + 1)}$ and the treatments effect were compared using transformed means. The ANOVA has been given in Appendix-XXII.

Results
and
Discussion

4. RESULTS AND DISCUSSION

The results emanated from the present investigation have been presented in this chapter through Tables and Graphs. An attempt has been made to establish cause and effect relationship of experimental findings justifying by giving possible scientific explanation and supportive evidences based on the available literature. The results have been discussed under following headings:

4.1 Crop weather interaction

4.2 Weed studies

4.3 Crop studies

4.4 Chemical studies

4.5 Economic studies

4.1. Crop weather interaction

The performance of any crop depends on the interaction between genetic and environmental factors. The environment plays an important role in influencing growth, development and ultimately the yield of a crop. Among the various environmental factors, weather parameters like ambient temperature, rainfall, sunshine hours and relative humidity play an important role.

Weather data depicted in Fig. 3.1 and appended in Appendix-I, revealed that mean weekly maximum and minimum temperature during wheat growing period (November to May) ranged from 12.0 to 33.5 °C and 2.4 to 20.9 °C during 2010-11, respectively. The mean weekly temperature ranged between 7.2 to 27.2 °C during 2010-11. It indicated that temperature during the crop cycle was favourable for germination, development and yield of wheat as ideal temperature range for successful wheat cultivation has been reported to be between 25 to 30 °C (Arnon 1972). The crop experienced well distributed rainfall of 450 mm in the crop growing period which lied in the optimum range of 360-630 mm (Reddy 2004). The highest weekly total rainfall of 108.8 mm was received in 7th Meteorological week. The mean weekly relative humidity during the crop season lied in

the range from 49 to 78 per cent. The mean weekly sunshine hours ranged from 2 to 10.5 hours during the growing season. The overall weather conditions were favourable for growth and development of wheat.

4.2 Weed studies

4.2.1 Surveillance and distribution of weed species

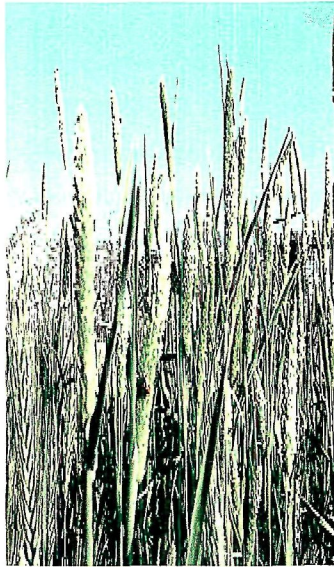
The experimental field was keenly monitored during crop growth phases to look for the occurrence of different weed species at the particular stage. The occurrence of weed species noticed at a particular stage of the crop, has been shown in Table 4.1. It was revealed that *Phalaris minor*, *Avena ludoviciana*, *Lolium temulentum*, *Vicia sativa*, *Anagallis arvensis* and *Coronopus didymus* have shown their occurrence at all the stages of crop growth. *Poa annua*, *Ranunculus arvensis* and *Stellaria media* were first observed at 90 DAS. *Ranunculus arvensis* withered before the harvest, whereas *Poa annua* and *Stellaria media* showed their occurrence up to harvest. *Oxalis latifolia* was noticed at 60 and 90 DAS. Thereafter it disappeared probably owing to inter and intra specific competition, *Alopecurus myosuroides*, *Tulipa* sp. and *Briza minor* were noticed at harvest only.

Table 4.1 Species wise occurrence of weeds in experimental field at different growth stages (x: presence of weeds)

Weed species	Stages of occurrence of weed (DAS)				
	60	90	120	150	Harvest
<i>Phalaris minor</i> Retz.	x	x	x	x	x
<i>Avena ludoviciana</i> Dur.	x	x	x	x	x
<i>Lolium temulentum</i> L.	x	x	x	x	x
<i>Vicia sativa</i> L.	x	x	x	x	x
<i>Anagallis arvensis</i> L.	x	x	x	x	x
<i>Coronopus didymus</i> L.	x	x	x	x	x
<i>Stellaria media</i> L.		x	x	x	x
<i>Poa annua</i> L.		x	x	x	x
<i>Ranunculus arvensis</i> L.		x	x	x	
<i>Oxalis latifolia</i> L.	x	x			
<i>Alopecurus myosuroides</i> Huds.					x
<i>Briza minor</i> L.					x
<i>Tulipa</i> sp.					x



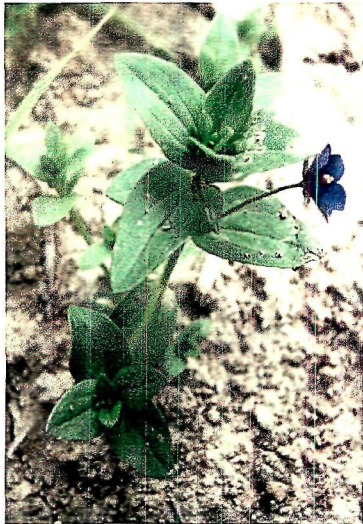
Lolium temulentum



Phalaris minor



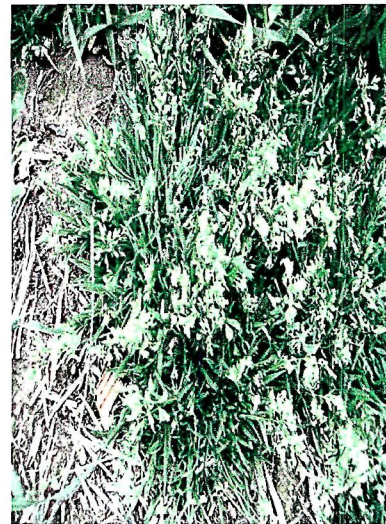
Avena ludoviciana



Anagallis arvensis



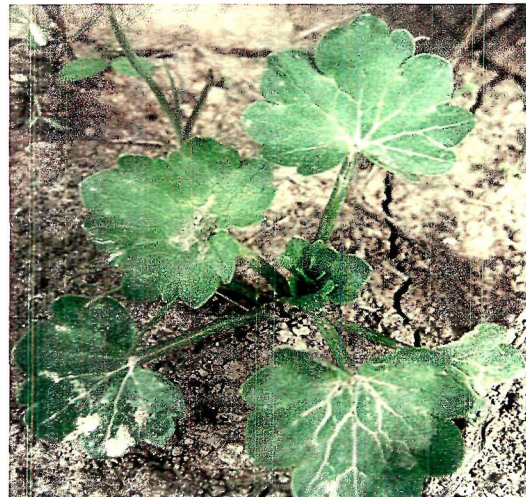
Vicia sativa



Poa annua



Coronopus didymus



Ranunculus arvensis

Plate 4.1 Major weeds of wheat

The proportion of major weed species in the weedy check at maximum weed population stage *i.e.* 90 days after sowing has been presented in Table 4.2. The data revealed that *Phalaris minor* and *Anagallis arvensis* were the major weeds constituting 60.8 and 21.4% of total weed population, respectively. *Avena ludoviciana*, *Lolium temulentum* and *Poa annua* constituted 4.7, 3.6 and 3.0% of total weed population, respectively. The other weeds showed their little infestation but as a whole constituted 6.5% of the total weed flora. Almost similar type of weed flora in wheat crop has also been reported by Thakur and Singh (1989) and Saini and Angiras (1991) under Palampur condition. Severe infestation by *Phalaris minor*, *Avena ludoviciana* and *Lolium temulentum* in wheat in Northern wheat growing states of the country has also been reported (Bhardwaj 1979).

Table 4.2 Species wise population of weeds in weedy check at maximum population (90 DAS)

Weed species	Population (m ⁻²)	Percentage of total
<i>Phalaris minor</i>	273.3	60.8
<i>Avena ludoviciana</i>	21.3	4.7
<i>Lolium temulentum</i>	16.0	3.6
<i>Poa annua</i>	13.3	3.0
<i>Anagallis arvensis</i>	96.0	21.4
Other broad leaf weeds	29.3	6.5
Total	449.2	100.00

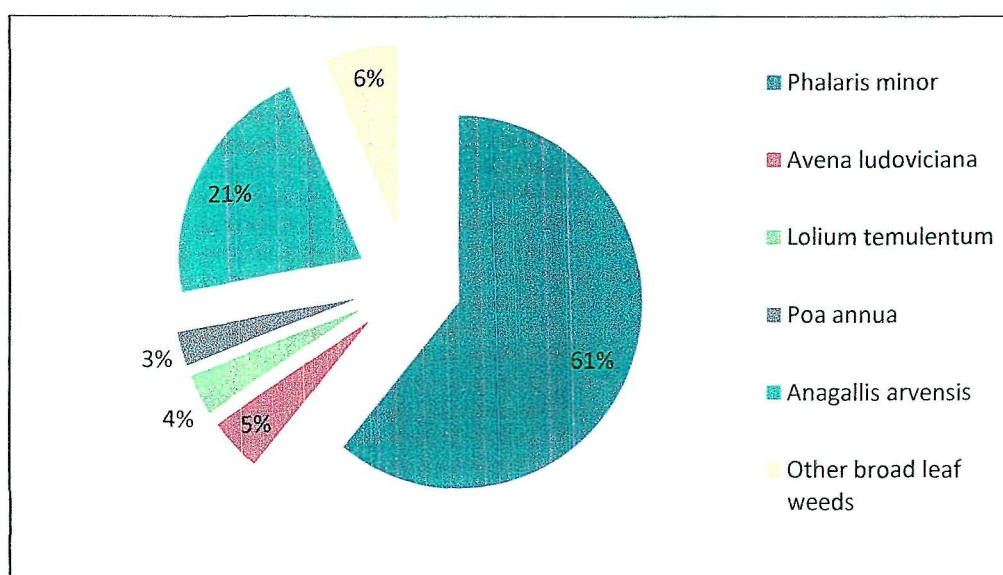


Fig. 4.1 Species wise population of weeds in weedy check at maximum population (90 DAS)

4.2.2 Weed count

The data on weed count have been recorded at 60, 90, 120, 150 DAS and at harvest. Fig. 4.2 to 4.7 show trend in count of weeds under different treatments. It was revealed that count of all weeds in general except *Avena ludoviciana* were maximum at 90 days after sowing (maximum count of *Avena ludoviciana* was at 120 DAS) and gradually decreased thereafter, probably owing to suppressive effect of vigorous crop growth. Therefore, data on weed count have been described at their maximum population stage *i.e.* 90 DAS. The data on remaining stages have been presented in Appendix-VI to XII.

4.2.2.1 *Phalaris minor*

All weed control treatments significantly reduced the population of *Phalaris minor* over weedy check (Table 4.3). 2, 4-D (500 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) are mainly broad-leaf herbicides. Obviously all these as well as mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) showed their little effect on *Phalaris minor*. The remaining treatments were comparable to weed free in reducing the count of *Phalaris minor* up to 90 DAS. The activity of pinoxaden (Chhokar *et al.* 2008b; Kaur *et al.* 2007; Yadav *et al.* 2009; Kumar *et al.* 2010), isoproturon (Chopra *et al.* 2001) and clodinafop (Singh *et al.* 2005; Jat *et al.* 2007) against *Phalaris minor* has been established well.

4.2.2.2 *Avena ludoviciana*

The population of *Avena ludoviciana* was significantly influenced under weed control treatments. All weed control treatments except 2, 4-D (500 g ha⁻¹) significantly reduced the population of *Avena ludoviciana* over weedy check (Table 4.3). Pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹) and pinoxaden (50 g ha⁻¹) were as good as weed free in reducing the population of *Avena ludoviciana* at 90 DAS. Similar observations with respect to pinoxaden alone or in combination with other herbicides on count of *Avena ludoviciana* were recorded (Kumar *et al.* 2010; Gowacki *et al.* 2007; Chhokar *et al.* 2008a; Malik *et al.* 2000). Clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) were comparatively less effective than other treatments in reducing its population.

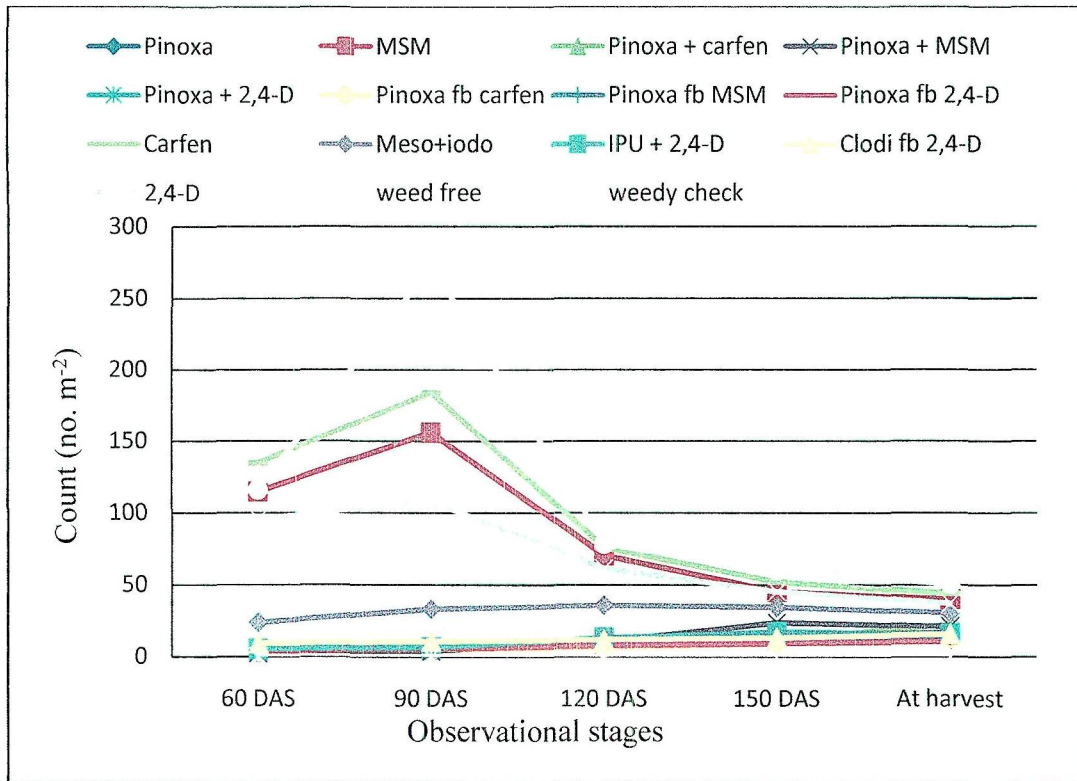


Fig. 4.2 Effect of weed control treatments on count of *Phalaris minor*

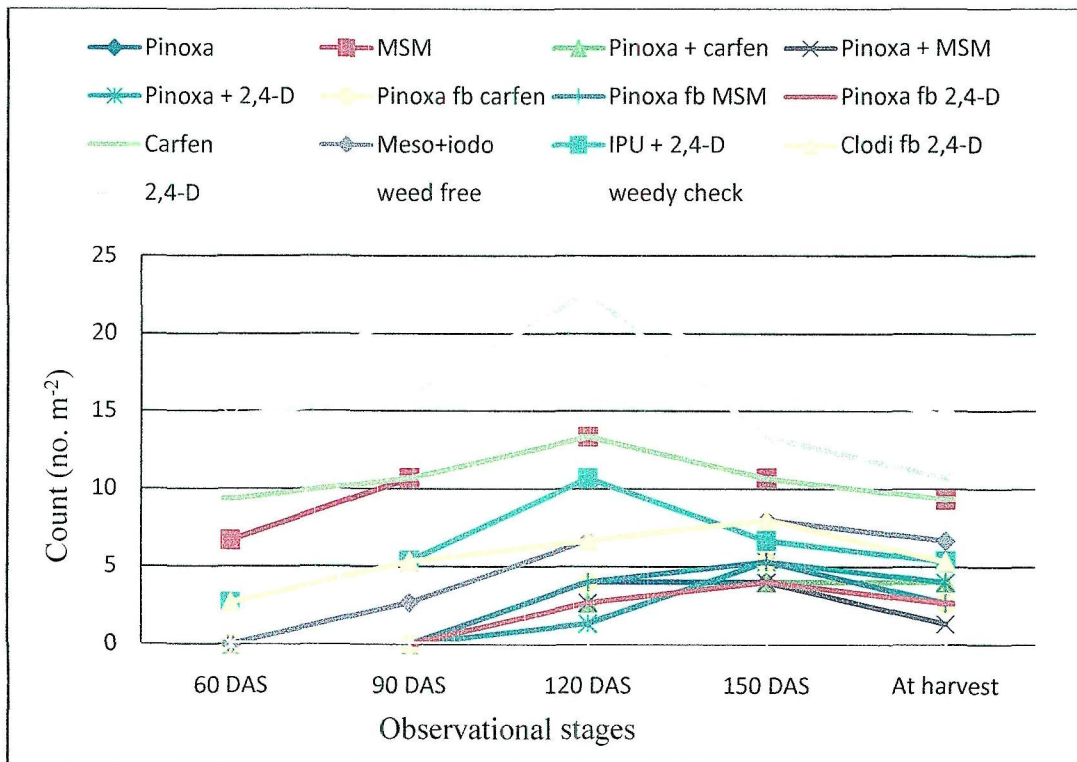


Fig. 4.3 Effect of weed control treatments on count of *Avena ludoviciana*

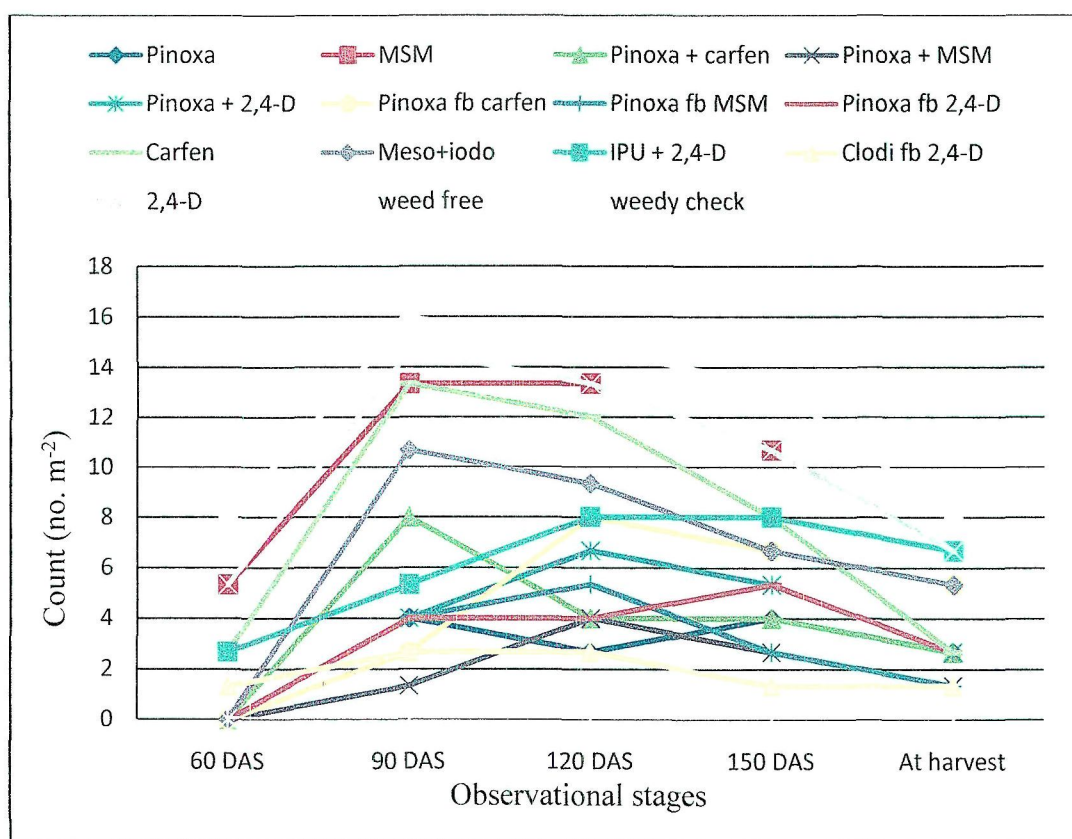


Fig. 4.4 Effect of weed control treatments on count of *Lolium temulentum*

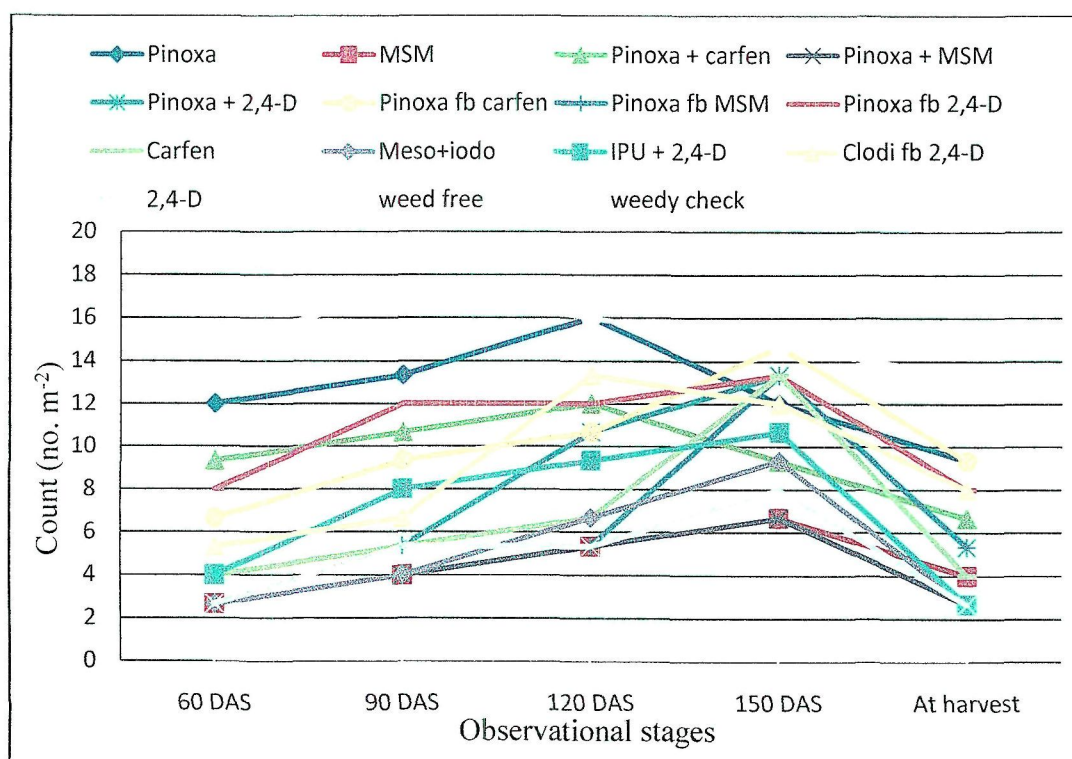


Fig. 4.5 Effect of weed control treatments on count of *Vicia sativa*

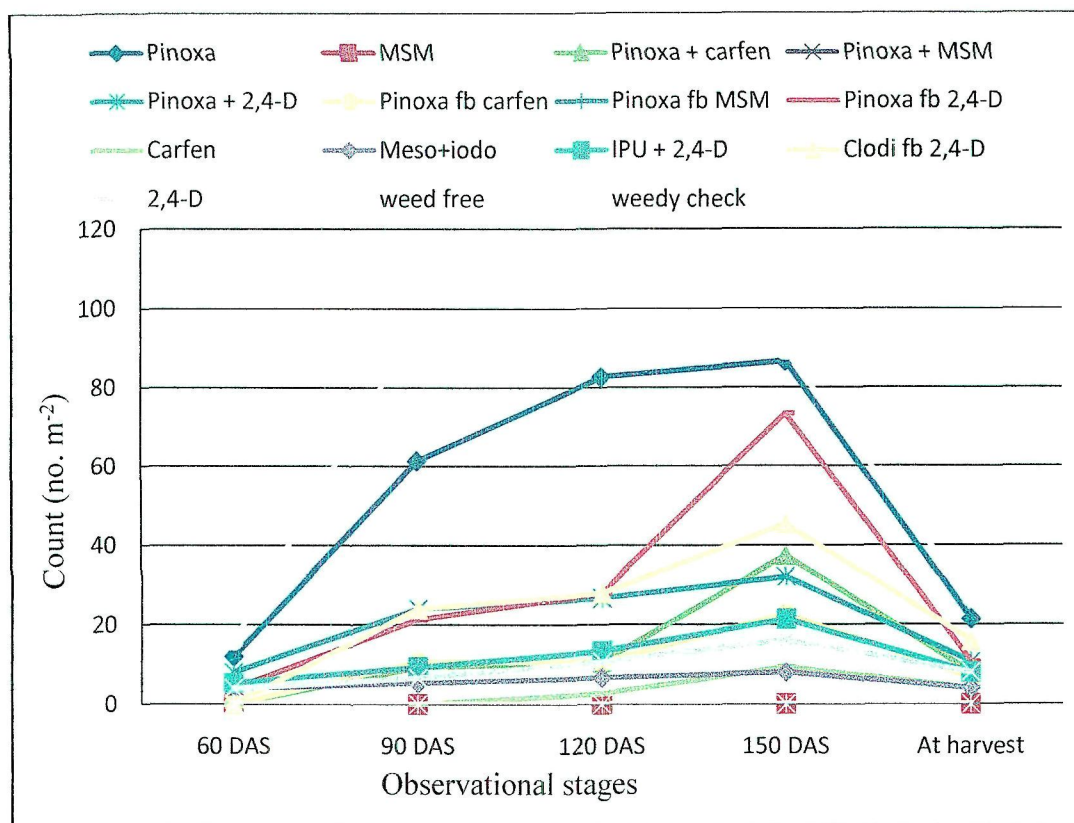


Fig. 4.6 Effect of weed control treatments on count of *Anagallis arvensis*

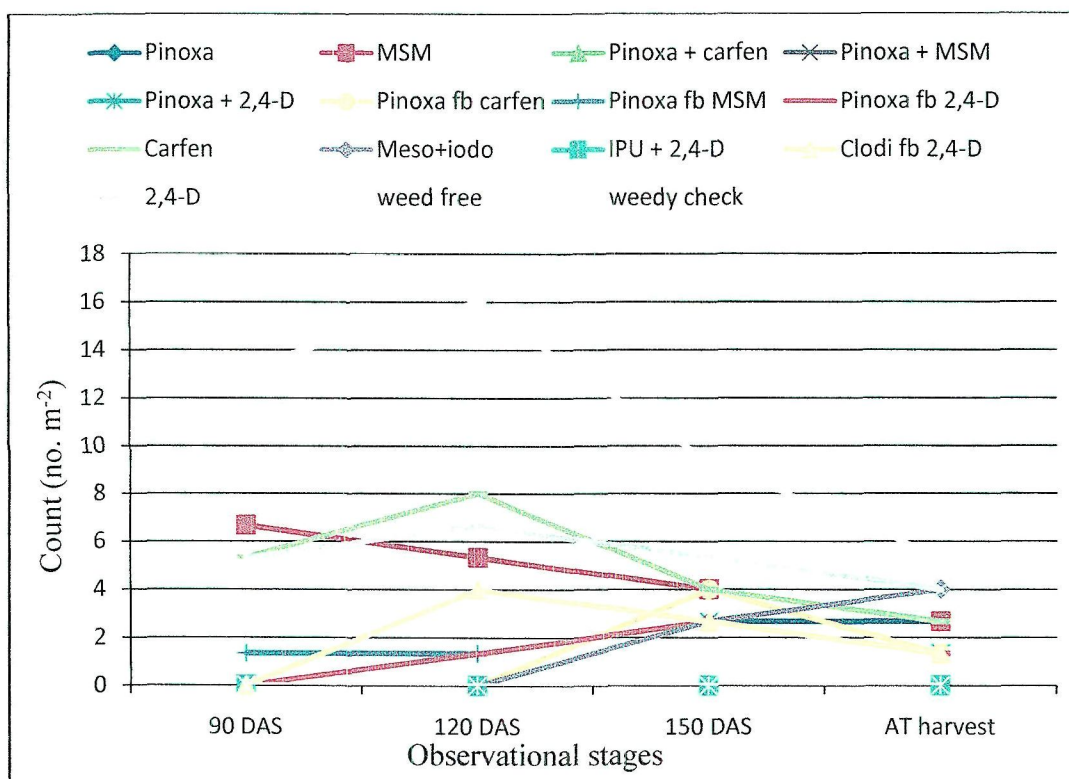


Fig. 4.7 Effect of weed control treatments on count of *Poa annua*

Table 4.3 Effect of weed control treatments on density (no. m⁻²) of weed species at maximum weed population stage *i.e.* 90 DAS

Treatment	Dose (g ha ⁻¹)	Weed species					
		<i>Phalaris</i>	<i>Avena</i>	<i>Lolium</i>	<i>Poa</i>	<i>Anagallis</i>	<i>Vicia</i>
Pinoxaden	50	2.8 (6.7)	1.0 (0.0)	2.1 (4.0)	1.0 (0.0)	7.6 (61.3)	3.8 (13.3)
Metsulfuron methyl	4	12.4 (156.0)	3.4 (10.7)	3.8 (13.3)	2.7 (6.7)	1.0 (0.0)	2.1 (4.0)
Pinoxaden + carfentrazone-ethyl	50 + 20	2.5 (5.3)	1.0 (0.0)	2.3 (5.3)	1.0 (0.0)	2.9 (9.3)	3.4 (10.7)
Pinoxaden + metsulfuron methyl	50 + 4	2.1 (4.0)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.0 (0.0)	2.1 (4.0)
Pinoxaden + 2, 4-D	50 + 500	2.3 (5.3)	1.0 (0.0)	2.1 (4.0)	1.0 (0.0)	4.9 (24.0)	2.3 (5.3)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	2.3 (5.3)	1.0 (0.0)	1.7 (2.7)	1.0 (0.0)	2.9 (10.7)	3.2 (9.3)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	3.0 (9.3)	1.0 (0.0)	2.2 (4.0)	1.4 (1.3)	1.0 (0.0)	2.3 (5.3)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	2.3 (5.3)	1.0 (0.0)	1.9 (4.0)	1.0 (0.0)	4.1 (21.3)	3.6 (12.0)
Carfentrazone-ethyl	20	13.4 (184.0)	3.4 (10.7)	3.7 (13.3)	2.3 (5.3)	1.0 (0.0)	2.3 (5.3)
Mesosulfuron + iodosulfuron	13 + 5	5.8 (33.3)	1.7 (2.7)	3.4 (10.7)	1.0 (0.0)	2.3 (5.3)	2.1 (4.0)
Isoproturon + 2, 4-D	1250 + 500	2.5 (6.7)	2.3 (5.3)	2.3 (5.3)	1.0 (0.0)	2.9 (9.3)	3.0 (8.0)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	3.4 (10.7)	2.3 (5.3)	1.8 (2.7)	1.0 (0.0)	5.0 (24.0)	2.5 (6.7)
2, 4-D	500	10.1 (108.0)	4.1 (16.0)	3.9 (14.7)	2.3 (5.3)	2.8 (6.7)	2.3 (5.3)
Weed free		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check		16.5 (273.3)	4.7 (21.3)	4.0 (16.0)	3.8 (13.3)	9.8 (96.0)	3.8 (13.3)
LSD		2.4	1.0	1.4	0.8	2.3	1.5

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parenthesis are the means of original values

4.2.2.3 *Lolium temulentum*

The population of *Lolium temulentum* was significantly influenced due to weed control treatments, (Table 4.3). Count of *Lolium temulentum* was significantly lower under pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹) and pinoxaden (50 g ha⁻¹) treated plots as compared to weedy check. Similar results were also obtained by Saini and Angiras (1991) under Palampur conditions. Mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), 2, 4-D (500 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) could not significantly reduce the count of this weed over weedy check.

4.2.2.4 *Vicia sativa*

Weed control treatments significantly affected the count of *Vicia sativa* (Table 4.3). Count of *Vicia sativa* was significantly lower under pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), 2, 4-D (500 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) treated plot as compared to weedy check. The effective control of this weed with metsulfuron methyl and carfentrazone-ethyl has also been reported by Kurchania *et al.* (2000) and Walia and Singh (2007). Pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), pinoxaden (50 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹) and pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹) could not significantly reduce its count over weedy check. This may probably be owing to late appearance of some flushes of the weed which escape herbicide application.

4.2.2.5 *Anagallis arvensis*

All weed control treatments except pinoxaden (50 g ha⁻¹) were significantly superior to weedy check against *Anagallis arvensis* (Table 4.3). As evident (Fig. 4.6), the main flush of *Anagallis arvensis* appeared around 90 DAS *i.e.* after the application of post-emergent herbicides, 2, 4-D adjudged to be least effective against the weed. It may

be seen from the fact that the treatments including 2, 4-D [Pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹) and clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹)] were not so effective against *Anagallis arvensis*. The rest of the treatments *viz.* pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), 2, 4-D (500 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) behaving statistically alike were comparable to weed free in reducing the count of *Anagallis arvensis*. The activity of metsulfuron methyl alone or in combination with other herbicides (Kurchania *et al.* 2000; Kumar *et al.* 2010; Sharma and Pahuja 2001) and carfentrazone (Singh *et al.* 2005; Jat *et al.* 2007) against *Anagallis arvensis* has been well established.

4.2.2.6 *Poa annua*

The population of *Poa annua* was significantly influenced due to weed control treatments (Table 4.3). Count of *Poa annua* was significantly lower under pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) and pinoxaden (50 g ha⁻¹) treated plots as compared to weedy check. Similar results were also obtained by Saini and Angiras (1991) under Palampur conditions. Metsulfuron methyl (4 g ha⁻¹), 2, 4-D (500 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) could not significantly reduce the count of this weed over weedy check.

4.2.2.6 Total weed count

Weed control treatments significantly influenced the total weed count (Table 4.4). Owing to reduction in species-wise weed count, all the weed control treatments resulted in significant reduction in total weed count as compared to weedy check. Pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) resulted in significantly lowest total weed count among herbicidal treatments and was statistically at par with weed free. The superiority of pinoxaden + metsulfuron methyl mixture in controlling weed has been documented

(Kumar *et al* 2010). Pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) and clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹) were the other superior treatments. 2, 4-D (500 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹) were least effective.

4.2.3 Total weeds dry weight

Data pertaining to progressive dry matter accumulation by weeds have been presented in Fig. 4.9. The figure revealed that in general, dry matter accumulation increased consistently up to 150 DAS, thereafter it declined gradually. The decline in weed dry weight was owed to withering of weeds. Data on weed dry weight at maximum dry matter stage *i.e.* 150 DAS have been given in Table 4.4. The weed dry weight at rest of the stages has been appended in Appendix-XIV. Similar to weed count, weed control treatments significantly decreased total weed dry weight as compared to weedy check. Removing the weeds whenever they appear under the weed free treatment resulted in complete elimination of weed competition as evident from this treatment that weed free resulted in lowest total weed dry weight. Pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹) remaining at par with pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) and pinoxaden + 2,4-D (50 + 500 g ha⁻¹) resulted in significantly lower total weed dry weight over rest of the herbicidal treatments. The superiority of pinoxaden + metsulfuron methyl in controlling weeds has been reported (Kumar *et al.* 2010). Pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), pinoxaden *fb* 2,4-D (50 *fb* 500 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹) behaving statistically alike were the next best treatments. Owing to synergetic enhancement or additive effects, herbicidal combinations in general were better than sole application of herbicides in effectively reducing the total weed dry weight.

4.2.4 Weed growth analysis

Data on growth rate of weeds (GR_w) from 90-120 DAS and relative growth rate of weeds (RGR_w) have been embodied in Table 4.4. Weed control treatments significantly influenced the GR_w and RGR_w.

Table 4.4 Effect of weed control treatments on total weed count (no. m⁻²), total weed dry matter accumulation (g m⁻²) and weed growth analysis

Treatment	Dose (g ha ⁻¹)	Total weed count (90 DAS)	Total weed dry matter (g m ⁻²) (150 DAS)	GR _w (g m ⁻² day ⁻¹) (90-120 DAS)	RGR _w (g g ⁻¹ day ⁻¹) (90-120 DAS)
Pinoxaden	50	10.8 (116.0)	11.6 (136.3)	0.528	0.043
Metsulfuron methyl	4	13.8 (193.3)	13.0 (169.6)	1.635	0.048
Pinoxaden + carfentrazone-ethyl	50 + 20	6.3 (38.7)	6.7 (44.4)	0.320	0.077
Pinoxaden + metsulfuron methyl	50 + 4	3.2 (9.3)	4.3 (18.4)	0.210	0.072
Pinoxaden + 2, 4-D	50 + 500	6.5 (41.3)	5.8 (37.6)	0.456	0.118
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	5.5 (30.7)	6.5 (42.5)	0.458	0.054
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	4.9 (24.0)	4.8 (23.4)	0.366	0.096
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	6.5 (44.0)	6.5 (44.7)	0.248	0.073
Carfentrazone-ethyl	20	14.8 (222.7)	12.4 (155.0)	2.364	0.045
Mesosulfuron + iodosulfuron	13 + 5	7.6 (57.3)	8.7 (77.2)	1.402	0.143
Isoproturon + 2, 4-D	1250 + 500	5.8 (34.7)	6.3 (39.6)	0.751	0.140
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	7.2 (50.7)	8.0 (63.2)	0.374	0.077
2, 4-D	500	12.4 (156.0)	13.8 (190.0)	3.338	0.067
Weed free		1.0 (0.0)	1.0 (0.0)	0.000	0.000
Weedy check		21.0 (445.3)	15.1 (228.8)	3.526	0.046
LSD		2.2	2.5	0.967	0.068

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parentheses are the means of original values

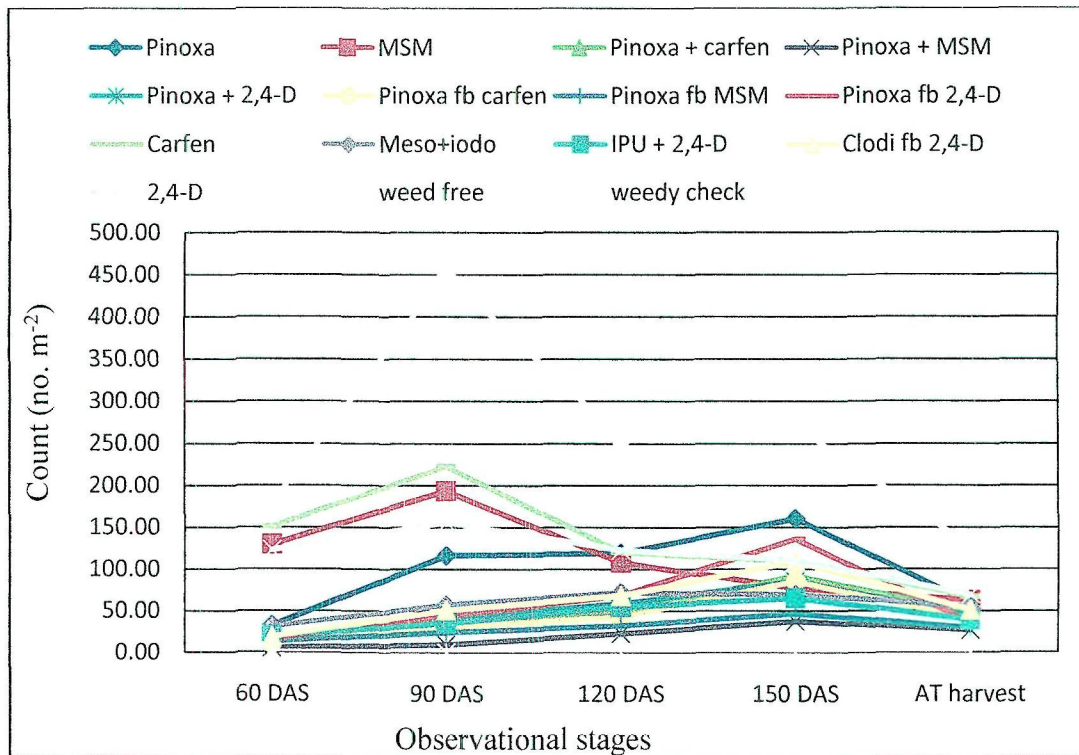


Fig. 4.8 Effect of weed control treatments on total weed count at different stages of observation

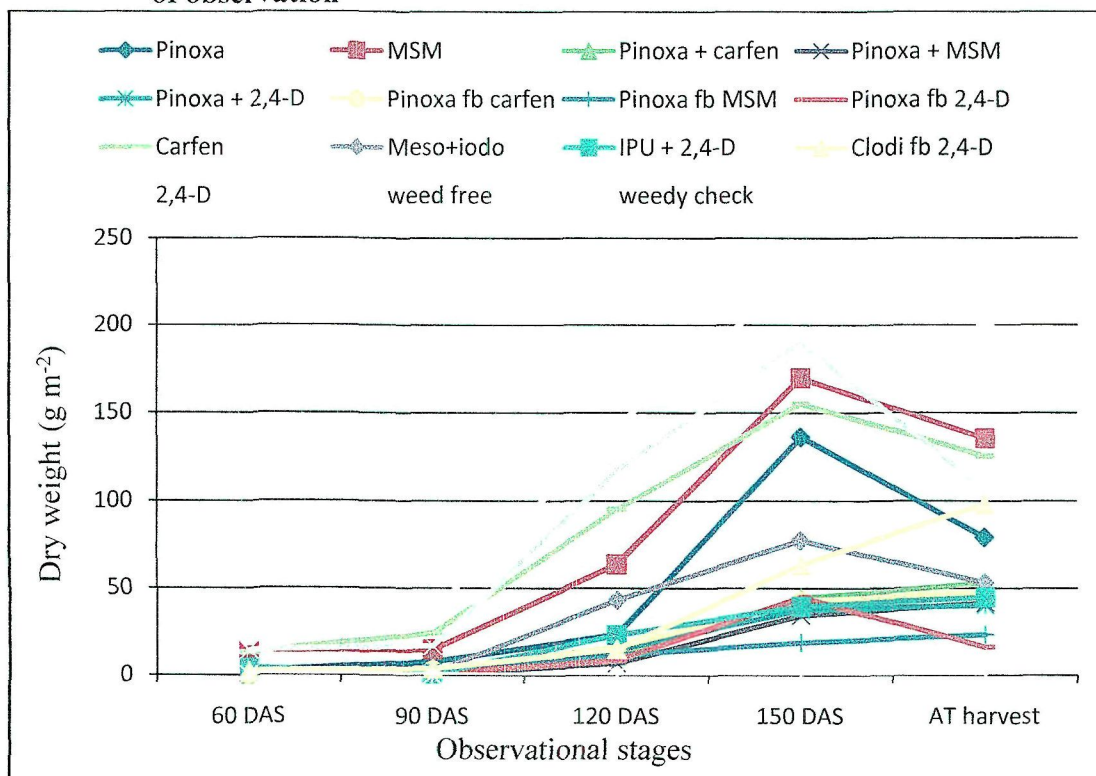


Fig. 4.9 Effect of weed control treatments on total weed dry matter accumulation at different stages of observation

All treatments except 2, 4-D (500 g ha^{-1}) had significantly lower GR_w over weedy check. All the herbicide combinations and pinoxaden (50 g ha^{-1}) were comparable to weed free in reducing the GR_w between 90-120 DAS. Sole application of metsulfuron methyl (4 g ha^{-1}) and carfentrazone-ethyl (20 g ha^{-1}) were less effective in influencing GR_w , though the former was superior to the later.

Relative growth rate of weeds was not significantly reduced by any treatment compared to weedy check. Pinoxaden + 2, 4-D ($50 + 500 \text{ g ha}^{-1}$), mesosulfuron + iodosulfuron ($13 + 5 \text{ g ha}^{-1}$) and isoproturon + 2, 4-D ($1250 + 500 \text{ g ha}^{-1}$) resulted in significantly higher RGR_w between 90-120 DAS over other treatments.

4.2.4 Weed control efficiency/Index

Data on weed control efficiency and weed control index as affected by weed control treatments have been presented in Table 4.5. Because of species-wise better control of weeds under the herbicide mixtures or sequence application, weed control efficiency or index under them was comparable to weed free. Application of herbicide alone gave poor control of weeds, therefore had lower weed control efficiency and weed control index. These results are in close conformity with findings of Yadav *et al.* (2009) and Chopra and Chopra (2005).

4.3 Crop studies

Data with regard to different aspects of growth, development, yield attributes and yield of wheat have been presented under this heading:

4.3.1 Growth studies

Observation of different growth parameters of wheat have been described in this section as follows:

4.3.1.1 Emergence count

Data of emergence count of wheat at 15 DAS (Table 4.6) revealed that weed control treatments had not significantly influenced the emergence. This indicates that the herbicides tested were selective at the normal rate.

Table 4.5 Effect of weed control treatments on weed control efficiency and weed control index at maximum weed population stages *i.e.* 90 DAS

Treatment	Dose (g ha ⁻¹)	Weed control efficiency (%)	Weed control index (%)
Pinoxaden	50	73.6	81.5
Metsulfuron methyl	4	55.3	57.7
Pinoxaden + carfentrazone-ethyl	50 + 20	91.4	96.0
Pinoxaden + metsulfuron methyl	50 + 4	97.8	98.7
Pinoxaden + 2, 4-D	50 + 500	90.7	98.0
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	92.2	92.4
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	92.8	98.4
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	90.7	97.5
Carfentrazone-ethyl	20	49.6	36.1
Mesosulfuron + iodosulfuron	13 + 5	86.7	96.9
Isoproturon + 2, 4-D	1250 + 500	91.8	98.5
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	85.4	90.2
2, 4-D	500	66.3	53.4
Weed free		100.0	100.0
Weedy check		0.0	0.0
LSD		11.5	16.8

Table 4.6 Effect of weed control treatments on emergence count (no./m row length) at 15 DAS and no. of tillers meter⁻² at different stages of observation

Treatment	Dose (g ha ⁻¹)	Emergence count (15 DAS)	No. of tillers m ⁻²		
			Tillering	Earing	Harvesting
Pinoxaden	50	36.7	203.5	260.5	214.6
Metsulfuron methyl	4	30.2	154.7	205.7	188.7
Pinoxaden + carfentrazone-ethyl	50 + 20	32.2	218.3	255.3	212.4
Pinoxaden + metsulfuron methyl	50 + 4	42.5	233.8	273.1	215.3
Pinoxaden + 2,4-D	50 + 500	42.7	220.5	260.5	210.2
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	40.2	213.1	256.8	212.4
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	35.8	223.5	263.4	214.6
Pinoxaden <i>fb</i> 2,4-D	50 <i>fb</i> 500	45.7	215.3	263.4	210.2
Carfentrazone-ethyl	20	42.7	148.0	209.4	185.7
Mesosulfuron + idosulfuron	13 + 5	42.5	212.4	259.7	199.8
Isoproturon + 2,4-D	1250 + 500	38.8	230.9	256.0	199.1
Clodinafop <i>fb</i> 2,4-D	60 <i>fb</i> 1000	36.0	213.1	236.1	207.2
2,4-D	500	50.8	156.9	207.9	182.0
Weed free		46.7	249.4	295.3	219.8
Weedy check		35.7	148.0	193.1	181.3
LSD		NS	49.9	22.8	8.0

4.3.1.2 Number of tillers m⁻²

The effect of treatments on number of tillers m⁻² has been presented in Table 4.6. In general, there was an increase in number of tillers m⁻² up to earing and thereafter, it decreased slightly by harvest. The treatments significantly affected the number of tillers m⁻² at all stages of observation. All treatments were significantly superior to weedy check in increasing the number of tillers m⁻². However, the extent of increase depended on the extent of elimination of competition under a particular treatment. Weed free resulted in highest number of tillers m⁻² at tillering and earing. However, pinoxaden (50 g ha⁻¹), pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹) and pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹) were comparable to weed free at harvest. The increase in number of tillers m⁻² under these treatments might be because of lower total weed count and weed dry weight at the critical time of competition.

4.3.1.3 Plant height

Data pertaining to effect of weed control treatments on plant height have been presented graphically in Fig. 4.10. From the figure it can be inferred that plant height increased progressively up to earing stage and it increased at a decreasing rate thereafter under all the treatments. A cursory glance at data in Table 4.7 revealed that weed control treatments have significant influence on the plant height at tillering and earing stages but it leveled off at harvest and was not significantly affected due to treatments.

Table 4.7 Effect of weed control treatments on plant height (cm) at different stages of observation

Treatment	Dose (g ha ⁻¹)	Plant height (cm)		
		Tillering	Earing	Harvesting
Pinoxaden	50	24.8	93.4	101.7
Metsulfuron methyl	4	27.9	92.8	104.7
Pinoxaden + carfentrazone-ethyl	50 + 20	26.1	92.4	103.1
Pinoxaden + metsulfuron methyl	50 + 4	27.9	94.1	103.1
Pinoxaden + 2, 4-D	50 + 500	24.7	91.3	102.5
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	27.6	93.9	102.7
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	27.0	91.9	103.9
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	26.3	92.5	103.4
Carfentrazone-ethyl	20	27.0	93.0	102.0
Mesosulfuron + iodosulfuron	13 + 5	24.8	93.5	104.3
Isoproturon + 2, 4-D	1250 + 500	27.9	94.5	104.7
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	26.3	93.7	101.7
2, 4-D	500	27.1	93.6	104.1
Weed free		28.3	95.7	106.5
Weedy check		20.1	86.3	97.3
LSD		3.5	2.8	NS

All weed control treatments being at par were significantly superior to weedy check in increasing crop height at tillering resulting in taller plants. This clearly indicates that removal of competition by one or the other mean had shown its influence on the growth of the crop. However, pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$), pinoxaden (50 g ha^{-1}), pinoxaden *fb* carfentrazone-ethyl ($50 \text{ fb } 20 \text{ g ha}^{-1}$), carfentrazone-ethyl (20 g ha^{-1}), mesosulfuron + iodosulfuron ($13 + 5 \text{ g ha}^{-1}$), isoproturon + 2, 4-D ($1250 + 500 \text{ g ha}^{-1}$), clodinafop *fb* 2, 4-D ($60 \text{ fb } 1000 \text{ g ha}^{-1}$), 2, 4-D (500 g ha^{-1}) alone and weed free had an edge over other treatments in influencing plant height of wheat at earing.

4.3.1.4 Dry matter accumulation by crop

The trend in progressive dry matter accumulation by wheat crop under different weed control treatments has been shown graphically in Fig. 4.11. Dry matter accumulation increased consistently with the advancement of crop growth. The rate of increase was lowest from 30-60 DAS. Then it increased consistently up to harvest. Wheat crop accumulated 1.3, 5.3, 26.0, 64.9 and 87.0% of total dry matter accumulation up to 30, 60, 90, 120 and 150 DAS, respectively.

The data on total dry matter accumulation by wheat crop by harvest as influenced by different treatments have been given in Table 4.8. Weed free remaining at par with pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$), pinoxaden *fb* metsulfuron methyl ($50 \text{ fb } 4 \text{ g ha}^{-1}$) and pinoxaden *fb* 2, 4-D ($50 \text{ fb } 500 \text{ g ha}^{-1}$) resulted in significantly higher dry matter accumulation over rest of the treatment. The reduction in population and dry weight of weeds under these treatments and higher weed control efficiency created favourable micro-environment for growth and development of wheat crop and thus increased the dry matter accumulation of wheat.

4.3.1.5 Crop growth analysis

Data pertaining to crop growth rate (CGR) and relative growth rate (RGR) of wheat crop have been embodied in Table 4.8. Weed control treatments did not significantly influence the CGR and RGR of wheat. This showed that rate of growth of wheat remained unaffected irrespective to variation in population and dry weight of weeds.

Table 4.8 Effect of weed control treatments on total crop dry matter accumulation (g m^{-2}) and crop growth analysis

Treatment	Dose (g ha^{-1})	Crop dry matter (At harvest)	Crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$) (90-120 DAS)	Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) (60-90 DAS)
Pinoxaden	50	1073.8	12.616	0.059
Metsulfuron methyl	4	929.4	12.104	0.053
Pinoxaden + carfentrazone-ethyl	50 + 20	1051.0	14.713	0.044
Pinoxaden + metsulfuron methyl	50 + 4	1078.0	14.089	0.058
Pinoxaden + 2, 4-D	50 + 500	1056.4	13.265	0.054
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1062.0	13.341	0.052
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1088.4	13.302	0.056
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1052.3	12.243	0.056
Carfentrazone-ethyl	20	942.9	12.686	0.052
Mesosulfuron + iodosulfuron	13 + 5	963.5	14.092	0.053
Isoproturon + 2, 4-D	1250 + 500	994.4	12.893	0.055
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1036.4	14.621	0.051
2, 4-D	500	938.9	11.738	0.048
Weed free		1095.8	13.062	0.053
Weedy check		715.5	10.935	0.046
LSD		34.21	NS	NS

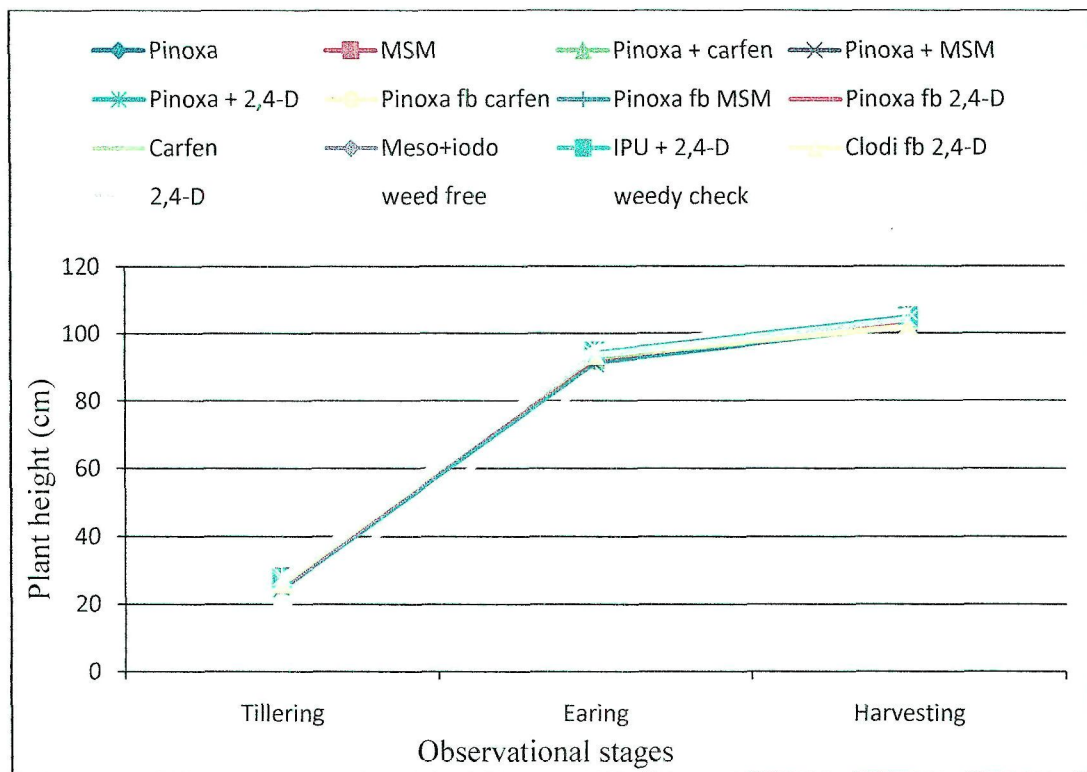


Fig. 4.10 Effect of weed control treatments on progressive plant height of wheat at different stages of observation

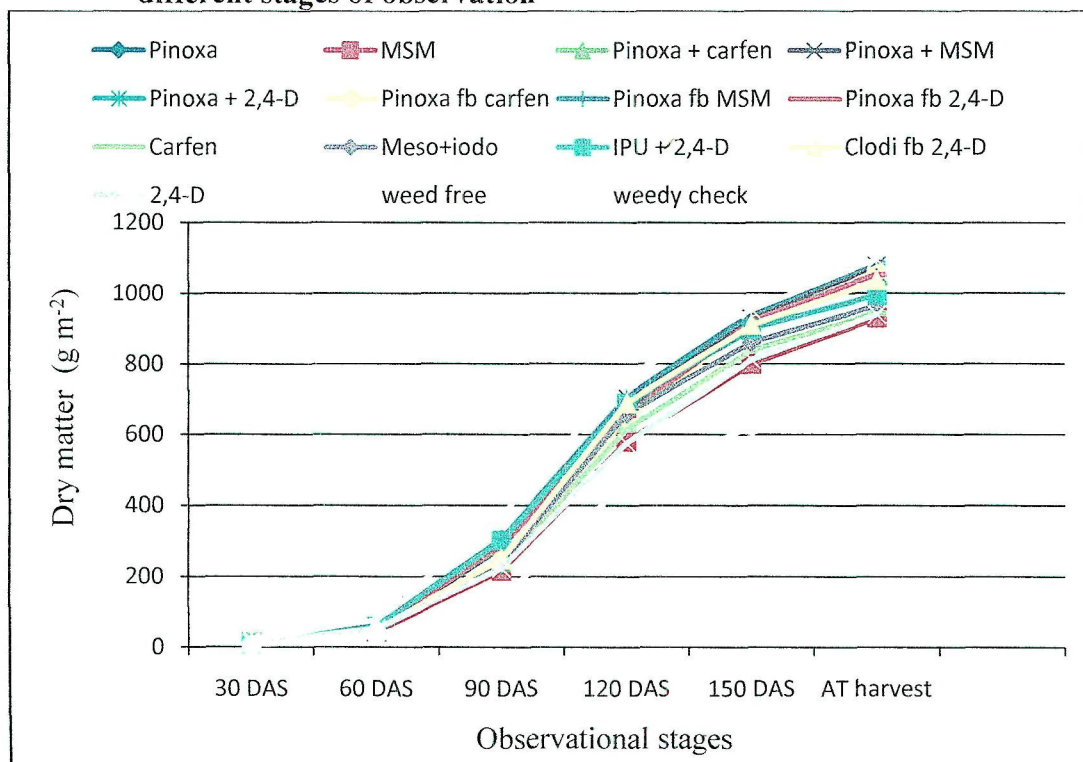


Fig. 4.11 Effect of weed control treatments on progressive dry matter accumulation by wheat at different stages of observation



Weedy check



Carfentrazone-ethyl (20 g ha^{-1})



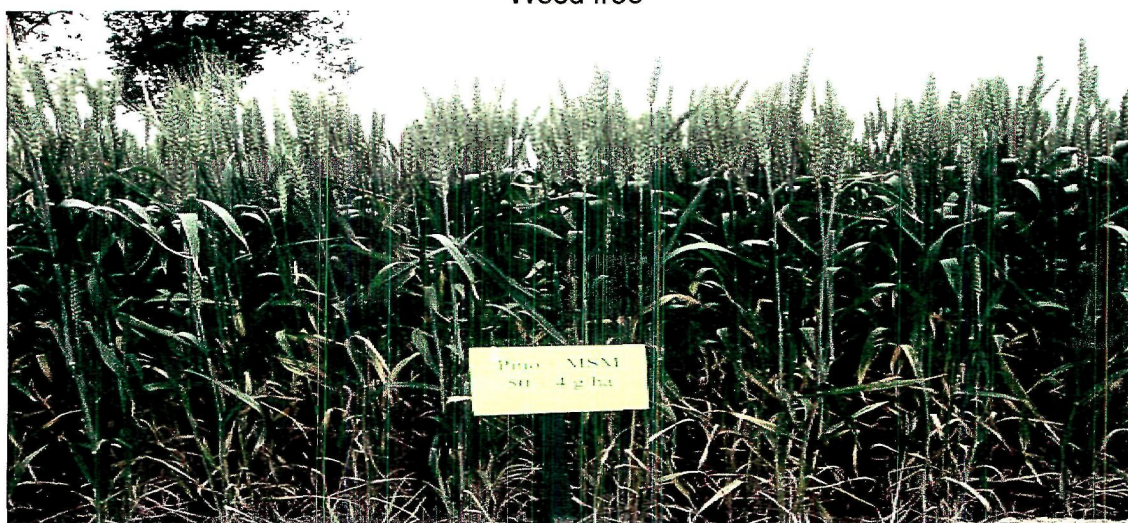
2, 4-D (500 g ha^{-1})

Plate 4.2 Effect of different treatments on weed flora

Contd....



Weed free



Pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$)



Pinoxaden *fb* metsulfuron methyl ($50 \text{ fb } 4 \text{ g ha}^{-1}$)

Contd....



Pinoxaden + 2, 4-D (50 + 500 g ha⁻¹)



Pinoxaden fb 2, 4-D (50 fb 500 g ha⁻¹)



Pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹)

Contd....



Clodinafop fb 2, 4-D (60 fb 1000 g ha⁻¹)



Pinoxaden (50 g ha⁻¹)



Metsulfuron methyl (4 g ha⁻¹)

4.3.2 Development studies

The effect of weed control treatments on phenophases of wheat *viz.* days taken to emergence, attainment of 50 per cent earing and crop maturity has been presented in Table 4.9. Weed control treatments did not significantly affect the days taken to emergence and maturity. However days to 50 per cent earing were significantly affected due to weed control treatments. All treatments except carfentrazone-ethyl (20 g ha⁻¹) and 2, 4-D (500 g ha⁻¹) significantly reduced the days to earing as compared to weedy check. This clearly showed that removal of competition has significant influence on advancing earing.

Table 4.9 Effect of weed control treatments on number of days taken to emergence, earing and maturity of wheat

Treatment	Dose (g ha ⁻¹)	Days to emergence	Days to earing	Days to maturity
Pinoxaden	50	15.3	117.3	185.0
Metsulfuron methyl	4	15.7	118.7	184.3
Pinoxaden + carfentrazone-ethyl	50 + 20	15.3	116.7	186.0
Pinoxaden + metsulfuron methyl	50 + 4	15.7	117.7	184.7
Pinoxaden + 2, 4-D	50 + 500	15.3	118.7	185.3
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	15.0	116.7	185.0
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	16.3	118.0	184.3
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	16.7	118.7	184.3
Carfentrazone-ethyl	20	16.7	119.3	184.3
Mesosulfuron + iodosulfuron	13 + 5	16.3	116.0	185.0
Isoproturon + 2, 4-D	1250 + 500	17.0	118.7	184.7
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	16.3	117.3	185.3
2, 4-D	500	15.7	119.0	184.3
Weed free		15.0	118.7	185.3
Weedy check		17.0	120.7	188.0
LSD		NS	1.9	NS

4.3.3 Yield attributes and yield

4.3.3.1 Yield contributing characters

Data on number of effective tillers m^{-2} , spikelets per spike, number of grains per spike and test weight of wheat have been presented in Table 4.10. A cursory glance at the data revealed that weed control treatments had significant effect on effective tillers m^{-2} , spikelets per spike, number of grain per spike and test weight.

Table 4.10 Effect of weed control treatments on yield contributing characters of wheat

Treatment	Dose (g ha ⁻¹)	Effective tiller m ⁻²	Spikelets/ Spike	No. of grains / Spike	Test weight (g)
Pinoxaden	50	204.2	19.7	42.6	43.4
Metsulfuron methyl	4	179.1	19.8	42.6	42.8
Pinoxaden + carfentrazone-ethyl	50 + 20	200.5	20.3	43.8	43.2
Pinoxaden + metsulfuron methyl	50 + 4	205.7	19.4	44.2	44.0
Pinoxaden + 2, 4-D	50 + 500	198.3	19.4	45.1	42.1
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	200.5	20.6	43.3	42.4
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	205.0	20.3	44.9	43.6
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	198.3	19.1	43.3	42.5
Carfentrazone-ethyl	20	177.6	20.1	42.5	42.0
Mesosulfuron + iodosulfuron	13 + 5	186.5	19.9	43.3	43.3
Isoproturon + 2, 4-D	1250 + 500	188.0	20.7	44.2	44.5
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	195.4	20.0	43.6	43.4
2, 4-D	500	174.6	20.1	42.7	42.6
Weed free		208.7	20.5	43.9	43.8
Weedy check		166.5	16.8	37.3	39.5
LSD		7.4	1.7	0.8	1.8

Owing to removal/reduction of competition right at early stages of crop growth, all treatments were significantly superior to weedy check in increasing effective tillers m^{-2} , spikelets per spike, number of grain per spike and test weight. All treatments were equally effective in increasing spikelets per spike and number of grain per spike. However, all herbicide combinations, weed free as well as pinoxaden (50 g ha⁻¹) alone was superior to metsulfuron methyl (4 g ha⁻¹), carfentrazone-ethyl (20 g ha⁻¹) and 2, 4-D (500 g ha⁻¹) in influencing effective tillers m^{-2} . Similarly combination of pinoxaden (50 g

ha⁻¹) with metsulfuron methyl (4 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), isoproturon + 2, 4-D (1250 +500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹) and weed free were superior to other treatments in influencing test weight. The superiority of herbicides combinations over alone application of herbicides in increasing yield attributes has been well documented (Kumar *et al.* 2010; Chopra and Chopra 2005).

4.3.3.2 Grain yield, straw yield, harvest index and weed index

The data on grain yield, straw yield, harvest index and weed index of wheat have been presented in Table 4.11.

4.3.3.2.1 Grain yield

Weed control treatments brought about significant variation in the grain yield of wheat. Owing to elimination or partial reduction in competition by weeds and subsequent increase in yield attributes was reflected in yield of wheat. Weed control treatments resulted in significantly higher grain yield over weedy check. Weed free gave highest grain yield. However, pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), pinoxaden (50 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹) and pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹) were as good as weed free. The removal of competition and subsequent increase in yield attributes and yield of wheat owing to herbicidal/weed free environment. 2, 4-D (500 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), carfentrazone-ethyl (20 g ha⁻¹) and mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) being statistically at par were less effective in influencing grain yield of wheat. Weeds in weedy check reduced grain yield of wheat by 36.97 and 36.55% over weed free and pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) respectively. Similar observations with respect to pinoxaden in combination with metsulfuron methyl on yield attributes and yield were recorded at Hisar (Kumar *et al.* 2010).

4.3.3.2.2 Straw yield

Straw yield in general followed the trend of grain yield. All weed control treatments were significantly superior to weedy check in increasing straw yield of wheat. Combinations of pinoxaden with other herbicides (tank mixture as well as sequential application) being at par to clodinafop *fb* 2,4-D (60 *fb* 1000 g ha⁻¹) and weed free resulted

in significantly higher straw yield over other treatments. 2, 4-D (500 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), carfentrazone-ethyl (20 g ha⁻¹) and mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) were comparatively less effective in increasing straw yield over weedy check. Straw is important food stuff for feeding livestock and weeds in weedy check reduced straw yield by 29.79% over pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹).

Table 4.11 Effect of weed control treatments on grain yield, straw yield, harvest index and weed index of wheat

Treatment	Dose (g ha ⁻¹)	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index	Weed index (%)
Pinoxaden	50	3684	7011	0.34	4.7
Metsulfuron methyl	4	3156	6111	0.34	18.2
Pinoxaden + carfentrazone-ethyl	50 + 20	3704	6799	0.35	4.1
Pinoxaden + metsulfuron methyl	50 + 4	3836	6931	0.36	0.6
Pinoxaden + 2, 4-D	50 + 500	3669	6852	0.35	4.9
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	3586	7011	0.34	7.1
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	3739	7116	0.34	3.1
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	3519	6905	0.34	8.7
Carfentrazone-ethyl	20	3066	6296	0.33	20.6
Mesosulfuron + iodosulfuron	13 + 5	3386	6190	0.35	12.2
Isoproturon + 2, 4-D	1250 + 500	3598	6138	0.37	6.8
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	3571	6693	0.35	7.4
2, 4-D	500	3046	6296	0.33	21.0
Weed free		3862	7037	0.35	0.0
Weedy check		2434	4866	0.33	36.9
LSD		426	671	0.02	10.9

4.3.3.2.3 Harvest index

Weed control treatments significantly affected the harvest index of wheat (Table 4.11). Isoproturon + 2, 4-D (1250 + 500 g ha⁻¹) remaining at par with pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) and weed free resulted in significantly higher harvest index over other treatments. The rest of the treatments were not significantly different from weedy check in influencing harvest index of wheat.

4.3.3.2.4 Weed index

Weed control treatments significantly influenced the weed index. It is a measure of yield depression due to the presence of weeds relative to weed free where competition was tended to be eliminated. Pinoxaden (50 g ha^{-1}) alone and in combination with other herbicides or followed with other herbicides, isoproturon + 2, 4-D ($1250 + 500 \text{ g ha}^{-1}$) and clodinafop *fb* 2, 4-D ($60 \text{ fb } 500 \text{ g ha}^{-1}$) had comparable yield as under weed free, thus also had comparable weed index. The other treatments were superior to weedy check in influencing yield and thereby weed index.

4.4 Chemical studies

The data pertaining to chemical studies *i.e.* NPK uptake by weeds and wheat as influenced by weed control treatments have been presented in this section (Table 4.12 and 4.13).

4.4.1 NPK uptake by weeds at harvest

The data on effect of treatments on nutrient uptake by weeds has been embodied in Table 4.12. Owing to significant reduction in dry weight, all weed control treatment significantly reduced N, P and K uptake by weeds as compared to weedy check. Pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$) and pinoxaden *fb* metsulfuron methyl ($50 \text{ fb } 4 \text{ g ha}^{-1}$) were as effective as weed free in reducing N, P and K uptake by weeds. Pinoxaden *fb* 2, 4-D ($50 \text{ fb } 500 \text{ g ha}^{-1}$) and pinoxaden + 2, 4-D ($50 + 500 \text{ g ha}^{-1}$) behaved statistically alike to weed free in influencing P uptake by weeds. In general, all herbicide combinations proved superior to alone application of herbicides in reducing the N, P and K uptake by weeds. Weeds in weedy check removed 37.4 kg ha^{-1} N, 6.9 kg ha^{-1} P and 46.8 kg ha^{-1} K depriving thereby the crop for that much amount of nutrients. Similar results have been reported by Pandey *et al.* (2001) and Khokhar and Nepalia (2010).

4.4.2 NPK uptake by wheat at harvest

The data on effect of treatments on N, P and K uptake by wheat at harvest have been embodied in Table 4.13.

All the weed control treatments significantly increased the N, P and K uptake by wheat over weedy check. Because of the higher grain and straw yield, weed free remaining at par with pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$), pinoxaden + carfentrazone-ethyl ($50 + 20 \text{ g ha}^{-1}$), pinoxaden + 2, 4-D ($50 + 500 \text{ g ha}^{-1}$), pinoxaden *fb*

Table 4.12 Effect of weed control treatments on N, P and K uptake (kg ha⁻¹) by total weeds at harvest

Treatment	Dose (g ha ⁻¹)	Nutrient uptake (kg ha ⁻¹)		
		Nitrogen	Phosphorus	Potassium
Pinoxaden	50	14.9	2.7	18.3
Metsulfuron methyl	4	25.1	4.6	31.1
Pinoxaden + carfentrazone-ethyl	50 + 20	7.9	1.4	9.8
Pinoxaden + metsulfuron methyl	50 + 4	4.4	0.8	5.7
Pinoxaden + 2, 4-D	50 + 500	5.6	1.0	7.0
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	8.1	1.5	10.1
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	4.6	0.9	5.8
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	5.7	1.1	7.0
Carfentrazone-ethyl	20	22.8	4.1	29.1
Mesosulfuron + iodosulfuron	13 + 5	9.4	1.7	11.9
Isoproturon + 2, 4-D	1250 + 500	7.4	1.4	9.2
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	15.2	2.9	18.9
2, 4-D	500	19.5	3.6	24.6
Weed free		0.0	0.0	0.0
Weedy check		37.4	6.9	46.8
LSD		5.4	1.1	6.7

Table 4.13 Effect of weed control treatments on N, P and K uptake (kg ha⁻¹) by wheat at harvest

Treatment	Dose (g ha ⁻¹)	Nutrient uptake (kg ha ⁻¹)		
		Nitrogen	Phosphorus	Potassium
Pinoxaden	50	115.9	21.3	86.1
Metsulfuron methyl	4	98.4	17.1	74.6
Pinoxaden + carfentrazone-ethyl	50 + 20	115.1	21.1	84.5
Pinoxaden + metsulfuron methyl	50 + 4	118.9	21.8	86.6
Pinoxaden + 2, 4-D	50 + 500	114.5	20.8	84.8
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	113.5	20.1	85.5
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	117.6	20.6	87.9
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	111.9	20.1	83.9
Carfentrazone-ethyl	20	98.3	16.7	76.1
Mesosulfuron + iodosulfuron	13 + 5	105.0	19.3	76.9
Isoproturon + 2, 4-D	1250 + 500	107.4	19.5	77.8
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	110.7	20.7	82.6
2, 4-D	500	97.2	16.7	75.8
Weed free		120.5	22.1	87.8
Weedy check		76.4	13.1	59.1
LSD		11.9	2.4	8.7

metsulfuron methyl (50 fb 4 g ha⁻¹) pinoxaden fb carfentrazone-ethyl (50 fb 20 g ha⁻¹) pinoxaden fb 2, 4-D (50 fb 500 g ha⁻¹) and pinoxaden (50 g ha⁻¹) alone resulted in significantly higher N, P and K uptake by crop. 2,4-D (500 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), isoproturon + 2,4-D (1250 + 500 g ha⁻¹), carfentrazone-ethyl (20 g ha⁻¹) and mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹) were less effective in influencing N, P and K uptake over other treatments. In general, all herbicide combination proved superior to alone application of herbicides in improving the N, P and K uptake by crop. The superiority of herbicide combination in influencing N, P and K uptake by crop has been documented (Khokhar and Nepalia 2010). Weed free resulted in 57.72, 68.70 and 48.56% higher N, P and K uptake over weedy check, respectively.

Nutrient uptake is the function of dry matter and nutrient content. Higher dry matter accumulation by wheat with application of pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) may be attributed to higher root spread and penetration in soil due to weed free environment. Also, lower N, P and K removal by weeds allowed wheat to grow vigorously and accumulated more biomass, which consequently led to higher uptake of these nutrients (Kumar and Das 2008). Higher dry matter accumulation by wheat under herbicidal treatments increased the nutrient uptake (Brar and Walia 2008; Pandey *et al.* 2001).

4.5 Economic studies

Data on gross returns, cost of cultivation, net returns and net returns per rupee invested as influenced by weed control treatments have been embodied in Table 4.14. The cost of cultivation of different treatments has been appended in Appendix-III and IV.

4.5.1 Gross returns

A perusal of data in Table 4.14 revealed that control of weeds through different weed control treatments increased the gross returns significantly over weedy check. Because of higher grain and straw yield, weed free, pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹), pinoxaden fb metsulfuron methyl (50 fb 4 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), pinoxaden + 2,4-D (50 + 500 g ha⁻¹), pinoxaden fb carfentrazone-ethyl (50 fb 20 g ha⁻¹), pinoxaden fb 2, 4-D (50 fb 500 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), clodinafop fb 2, 4-D (60 fb 1000 g ha⁻¹) and pinoxaden 50 g ha⁻¹ resulted

in higher gross returns as compared to rest of the treatments. In general herbicide combinations were better than herbicides alone but grass killers had an edge over broad-leaf killers because grassy weeds constituted more proportion of total weeds in experimental field.

4.5.2 Cost of cultivation

Data on cost of cultivation of different weed control treatments have been embodied in Table 4.14. Cost of cultivation was higher for weed free treatment due to more labour used in weeding and minimum under weedy check.

4.5.3 Net returns

Weed control treatments resulted in significantly higher net returns over weedy check. Net returns accrued under different treatments followed almost the same trend as gross returns. Net returns from weed free treatment was lower as compared to other weed control treatment due to higher cost of cultivation. Application of pinoxaden + metsulfuron methyl at 50 + 4 g ha⁻¹ (43542 Rs. ha⁻¹) resulted in highest net returns which was 112.72 per cent higher over weedy check. Pinoxaden *fb* metsulfurono-methyl 50 *fb* 4 g ha⁻¹ (42475 Rs. ha⁻¹) was the next superior treatment which increased net returns to the tune of 107.51 per cent over weedy check.

4.5.4 Net returns per rupee invested

Weed control treatments were superior to weedy check in influencing net returns per rupee invested. Similar results were reported by Kumar *et al.* (2011), Nadeem *et al.* (2007) and Sinha and Singh (2004) and they also obtained higher net returns with better control of weeds.

Application of pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) resulted in significantly higher net returns per rupee invested. However, this treatment was at par with pinoxaden *fb* metsulfuron methyl (50 *fb* 4 g ha⁻¹), pinoxaden (50 g ha⁻¹), pinoxaden + carfentrazone-ethyl (50 + 20 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), pinoxaden + 2, 4-D (50 + 500 g ha⁻¹), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g ha⁻¹), pinoxaden *fb* 2, 4-D (50 *fb* 500 g ha⁻¹) and isoproturon + 2, 4-D (1250 + 500 g ha⁻¹). Weed free treatment gave higher gross and net returns but had lower net returns per rupee invested than all herbicidal treatments due to higher cost involved in labour.

Table 4.14 Effect of weed control treatments on gross returns (Rs. ha⁻¹), net returns (Rs. ha⁻¹), cost of cultivation (Rs. ha⁻¹) and net returns per rupee invested in wheat

Treatment	Dose (g ha ⁻¹)	Gross returns (Rs. ha ⁻¹)	Cost of cultivation (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)	Net returns per rupee invested
Pinoxaden	50	69307	27071	42236	1.56
Metsulfuron methyl	4	59793	27056	32737	1.21
Pinoxaden + carfentrazone-ethyl	50 + 20	68677	27546	41131	1.49
Pinoxaden + metsulfuron methyl	50 + 4	70688	27146	43542	1.60
Pinoxaden + 2, 4-D	50 + 500	68501	27203	41298	1.52
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	68201	28266	39935	1.41
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	70341	27866	42475	1.52
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	67026	27923	39103	1.40
Carfentrazone-ethyl	20	59526	27456	32070	1.17
Mesosulfuron + iodosulfuron	13 + 5	62688	27043	35645	1.32
Isoproturon + 2, 4-D	1250 + 500	64846	27588	37258	1.35
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	66772	28134	38639	1.37
2, 4-D	500	59305	27113	32192	1.19
Weed free		71407	35861	35546	0.99
Weedy check		46730	26261	20469	0.78
LSD		7077	-	7077	0.25

***S*ummary
and
*C*onclusions**

5. SUMMARY AND CONCLUSIONS

The present investigation was carried out at Palampur (32°6' N latitude, 76°3' E longitude and 1290 meters altitude) during *Rabi* 2010-11. The Soil of the test site was silty clay loam in texture, acidic in reaction, low in available nitrogen, medium in available phosphorus and high in available potassium status.

Fifteen weed control treatments *viz.* pinoxaden (50 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹), carfentrazone-ethyl (20 g ha⁻¹) and 2, 4-D (500 g ha⁻¹) alone, pinoxaden (50 g ha⁻¹) with and before carfentrazone-ethyl (20 g ha⁻¹), metsulfuron methyl (4 g ha⁻¹) and 2, 4-D (500 g ha⁻¹), isoproturon + 2, 4-D (1250 + 500 g ha⁻¹), clodinafop *fb* 2, 4-D (60 *fb* 1000 g ha⁻¹), mesosulfuron + iodosulfuron (13 + 5 g ha⁻¹), weed free and weedy check were tested in randomized block design with 3 replications.

In the experimental field, *Phalaris minor*, *Avena ludoviciana*, *Lolium temulentum*, *Poa annua*, *Vicia sativa*, *Anagallis arvensis* and *Coronopus didymus* were the important weeds found growing in association with wheat crop. Grassy weeds were more pre-dominant than broad-leaf weeds.

Pinoxaden (50 g ha⁻¹) effectively controlled grassy weeds *viz.* *Phalaris minor*, *Avena ludoviciana*, *Lolium temulentum* and *Poa annua* as compared to clodinafop-propargyl (60 g ha⁻¹) and isoproturon (1250 g ha⁻¹). Application of metsulfuron methyl (4 g ha⁻¹) provided better control of broad-leaf weeds *viz.* *Vicia sativa*, *Anagallis arvensis* and *Coronopus didymus* as than 2, 4-D (500 g ha⁻¹) and carfentrazone-ethyl (20 g ha⁻¹). Pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) provided excellent control of both grassy and broad-leaf weeds and resulted in highest total weed control efficiency of 97.82 per cent.

Pinoxaden + metsulfuron methyl (50 + 4 g ha⁻¹) reduced N, P and K uptake by weeds by 88.23, 88.40 and 87.82 per cent, respectively over weedy check and also gave lowest weed growth rate while pinoxaden (50 g ha⁻¹) resulted in lowest relative growth rate of weeds.

Combined application of grassy and broad-leaf herbicides as tank mixture or in sequence at one week interval was comparable to weed free for dry matter accumulation by crop, yield attributes and grain yield.

In general, herbicide combinations were superior to alone application of herbicides in influencing the nutrient uptake by crop. Significantly higher N, P and K uptake by crop were obtained with pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$).

Weeds in the weedy check reduced grain yield by 36.97 per cent in comparison to weed free. Application of pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$) resulted in highest net returns (43542 Rs. ha^{-1}) and B: C ratio (1.60).

CONCLUSIONS

Tank mix application of pinoxaden + metsulfuron methyl ($50 + 4 \text{ g ha}^{-1}$) provided effective control of mixed weed flora resulted in significantly higher grain yield, highest net returns (43542 Rs. ha^{-1}) and net returns per rupee invested (1.60). Thus, combination approach (tank mixed or sequential) is the better option for the control of mixed weed flora to obtain higher yield.

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Appendices

APPENDICES

Appendix-I Mean weekly meteorological data at Palampur (Nov. 2010 to May 2011)

Standard week No.	Max Temp (°C)	Min Temp (°C)	Relative Humidity (%)	Rainfall (mm)	Sunshine (hours)
44	23.73	10.56	63.21	0.00	8.49
45	24.51	10.59	61.79	0.00	9.37
46	23.94	9.76	52.86	1.20	9.46
47	21.17	8.40	62.36	4.00	7.03
48	20.26	7.17	71.93	0.00	8.43
49	19.60	5.77	55.57	0.00	8.71
50	17.70	4.74	66.07	0.00	7.00
51	18.91	4.14	52.21	0.00	8.64
52	16.80	4.60	59.14	91.20	6.14
1	15.70	2.93	58.71	5.80	8.53
2	17.14	4.67	53.50	0.00	7.03
3	12.00	2.44	68.21	58.20	4.17
4	16.09	3.51	63.00	0.00	8.64
5	18.06	6.49	59.43	1.00	5.00
6	19.11	7.64	57.35	23.00	4.00
7	14.29	6.53	77.79	108.80	2.00
8	16.83	5.86	67.29	1.00	4.50
9	15.07	6.06	76.50	38.80	2.29
10	19.46	7.56	54.93	7.70	7.14
11	24.41	11.24	54.00	0.00	8.79
12	24.79	11.66	49.14	0.00	8.00
13	25.89	12.20	50.07	5.40	8.21
14	22.73	10.50	57.30	5.00	6.14
15	24.43	12.64	64.29	5.60	5.86
16	24.03	11.83	59.57	80.10	7.14
17	28.67	17.01	55.29	0.00	10.50
18	31.61	19.21	62.07	10.00	9.71
19	30.43	18.79	58.36	2.60	9.31
20	33.54	20.90	67.93	0.60	8.57

Appendix-II Herbicides detail

1. Clodinafop-propargyl

(1)	Herbicide group	:	Aryloxyphenoxy propionates
(2)	Molecular formula	:	C ₁₄ H ₁₁ ClFNO ₄
(3)	Structural formula	:	
(4)	IUPAC name	:	(R)-2-[4-(5-chloro-3-fluoro-2-pyridyloxy)phenoxy]propionic acid
(5)	Mode of action	:	Clodinafop-propargyl is absorbed by the leaves and rapidly translocated to the growing points of leaves and stems. It interferes with the production of fatty acids by Inhibition of acetyl CoA carboxylase which needed for plant growth in susceptible grassy weeds.

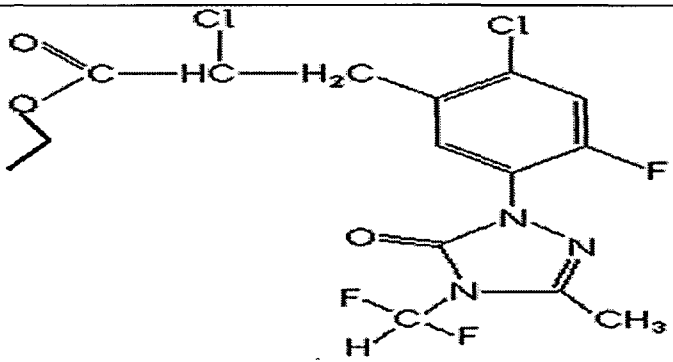
2. Pinoxaden

(1)	Herbicide group	:	Phenylpyrazolin
(2)	Molecular formula	:	$C_{23}H_{32}N_2O_4$
(3)	Structural formula	:	
(4)	IUPAC name	:	8-(2,6-diethyl- <i>p</i> -tolyl)-1,2,4,5-tetrahydro-7-oxo-7 <i>H</i> -pyrazolo[1,2- <i>d</i>][1,4,5]oxadiazepin-9-yl-2,2-dimethylpropionate
(5)	Mode of action	:	After uptake, pinoxaden interferes with the lipid metabolism in plant cells. The herbicide acts by inhibiting the enzyme Acetyl-CoA-Carboxylase (ACCase), interrupting the synthesis of fatty acids and a final consequence interrupts the formation of biomembranes.

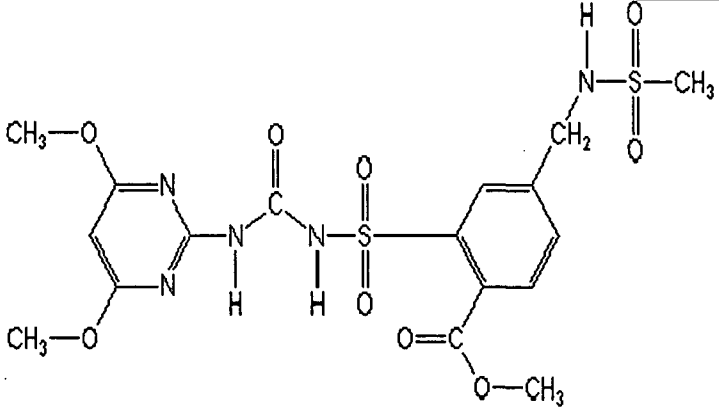
3. Metsulfuron methyl (MSM)

(1)	Herbicide group	:	Triazinylsulfonylurea_herbicides
(2)	Molecular formula	:	$C_{14}H_{15}N_5O_6S$
(3)	Structural formula	:	
(4)	IUPAC name	:	Methyl 2-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoyl sulfamoyl)benzoate
(5)	Mode of action	:	Inhibiting acetolactate synthase (acetoxyacid synthase), the first enzyme in the synthetic pathways for valine, leucine and isoleucine. This has a number of consequences including a reduction in nucleic acid synthesis which causes effects in the meristem.

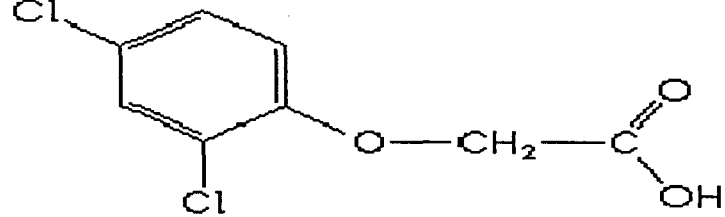
4. Carfentrazone-ethyl

(1)	Herbicide group	:	Phenyl triazolinones herbicides
(2)	Molecular formula	:	$C_{15}H_{14}Cl_2F_3N_3O_3$
(3)	Structural formula	:	
(4)	IUPAC name	:	Ethyl (<i>RS</i>)-2-chloro-3-{2-chloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1 <i>H</i> -1,2,4-triazol-1-yl]-4-fluorophenyl}propionate
(5)	Mode of action	:	Inhibiting acetolactate synthase (acetohydroxyacid synthase), the first enzyme in the synthetic pathways for valine, leucine and isoleucine. This has a number of consequences including a reduction in nucleic acid synthesis which causes effects in the meristem.

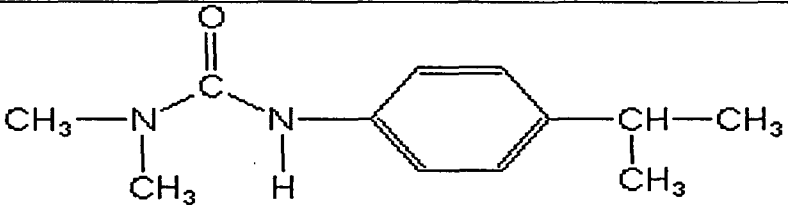
5. Mesosulfuron methyl

(1)	Herbicide group	:	Pyrimidinylsulfonyleureas
(2)	Molecular formula	:	$C_{17}H_{21}N_5O_9S_2$
(3)	Structural formula	:	
(4)	IUPAC name	:	Methyl 2-[3-(4,6-dimethoxy-pyrimidin-2-yl)-ureidosulfonyl]-4-methanesulfonamidomethyl-benzoate
(5)	Mode of action	:	The chemical works by inhibiting the enzyme acetolactate synthase (ALS), which leads to depletion of key amino acids that are necessary for protein synthesis and plant growth.

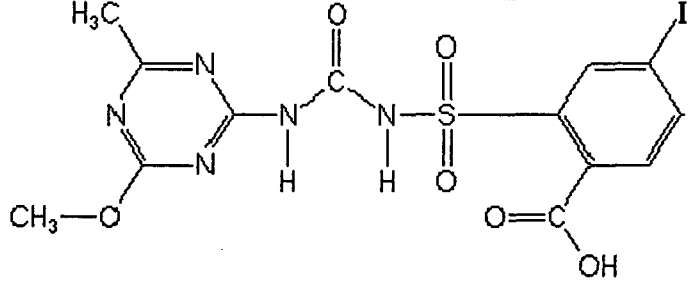
6. 2, 4-D

(1)	Herbicide group	:	Phenoxyalkanoic acid
(2)	Molecular formula	:	$C_8H_6Cl_2O_3$
(3)	Structural formula	:	
(4)	IUPAC name	:	(2,4-dichlorophenoxy)acetic acid
(5)	Mode of action	:	Responsible for excessive cell division and cell enlargement. Blending of stem takes place which is called epinasty, interfere with translocation of photosynthates via phoem vessels and malformed growth.

7. Isoproturon

(1)	Herbicide group	:	Substituted urea herbicide
(2)	Molecular formula	:	$C_{12}H_{18}N_2O$
(3)	Structural formula	:	
(4)	IUPAC name	:	3-(4-isopropylphenyl)-1,1-dimethylurea or 3- <i>p</i> -cumenyl-1,1-dimethylurea
(5)	Mode of action	:	Inhibit photosynthetic electron transport in photosystem-II.

8. Iodosulfuron

(1)	Herbicide group	:	Triazinylsulfonyl ureas
(2)	Molecular formula	:	$C_{13}H_{12}IN_5O_6S$
(3)	Structural formula	:	
(4)	IUPAC name	:	4-iodo-2-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)carbamoylsulfamoyl]benzoic acid
(5)	Mode of action	:	The chemical works by inhibiting the enzyme acetolactate synthase (ALS), which leads to depletion of key amino acids that are necessary for protein synthesis and plant growth.

Appendix-III Components of cost of cultivation

Particulars	Quantity	Rate (Rs.)	Amount (Rs.)
A. Land preparation			
1. Ploughing	8 hrs	320/hr	2560.00
2. Labour	10 Man days	120/man day	1200.00
B. Cost of fertilizers			
1. 120 kg N through Urea (46% N)	260.9 kg	4.83/kg	1260.15
2. 60 kg P through SSP (16% P ₂ O ₅)	375.0 kg	6.30/kg	2362.50
3. 30 kg K through MOP (60% K ₂ O)	50.0 kg	5.07/kg	253.50
4. Labour (Top dressing)	4 man days	120/man day	480.00
C. Cost of seed and sowing			
1. Cost of seed	100 kg	20/kg	2000.00
2. Labour	20 man days	120/man day	2400.00
D. Cost of plant protection measures			
1. Hexaconazole	750 ml	230/100 ml	1725.00
2. Labour	2 man days	120/man day	240.00
E. Cost of irrigation			
1. Pre sowing irrigation	2 man days	120/man day	240.00
2. Other irrigations (5)	10 man days	120/man day	1200.00
3. Water charges	96 hrs	65/hr	6240.00
F. Harvesting and Threshing	30 man days	120/man day	3600.00
G. Overhead cost			500.00
Total			26261.15

Appendix-IV (A) Variable expenses under different treatments

Treatment	Doses (ha ⁻¹)	Unit	Rates (Rs. kg ⁻¹)	Cost of herbicides (Rs.)	Spray cost (Rs.)	Total cost (Rs.)
T ₁ Pinoxaden	50	g	1800	90	720	810
T ₂ Metsulfuron methyl	4	g	18750	75	720	795
T ₃ Pinoxaden + carfentrazone-ethyl	50 + 20	g	1800 + 23750	565	720	1285
T ₄ Pinoxaden + metsulfuron methyl	50 + 4	g	1800 + 18750	165	720	885
T ₅ Pinoxaden + 2, 4-D	50 + 500	g	1800 + 264	222	720	942
T ₆ Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	g	1800 + 23750	565	1440	2005
T ₇ Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	g	1800 + 18750	165	1440	1605
T ₈ Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	g	1800 + 264	222	1440	1662
T ₉ Carfentrazone-ethyl	20	g	23750	475	720	1195
T ₁₀ Mesosulfuron + iodosulfuron	13 + 5	g	3438	62	720	782
T ₁₁ Isoproturon + 2, 4-D	1250 + 500	g	380 + 264	607	720	1327
T ₁₂ Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	g	2813 + 264	433	1440	1873
T ₁₃ 2, 4-D	500	g	264	132	720	852
T ₁₄ Weed free	80	man days	120	-	-	9600
T ₁₅ Weedy check	-	-	-	-	-	-

(B) Cost of cultivation of individual treatments (Rs. ha⁻¹)

Treatment	Doses (g ha ⁻¹)	Cost of cultivation (Rs. ha ⁻¹)
T ₁ Pinoxaden	50	27071
T ₂ Metsulfuron methyl	4	27056
T ₃ Pinoxaden + carfentrazone-ethyl	50 + 20	27546
T ₄ Pinoxaden + metsulfuron methyl	50 + 4	27146
T ₅ Pinoxaden + 2, 4-D	50 + 500	27203
T ₆ Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	28266
T ₇ Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	27866
T ₈ Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	27923
T ₉ Carfentrazone-ethyl	20	27456
T ₁₀ Mesosulfuron + iodosulfuron	13 + 5	27043
T ₁₁ Isoproturon + 2, 4-D	1250 + 500	27588
T ₁₂ Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	28134
T ₁₃ 2, 4-D	500	27113
T ₁₄ Weed free	-	35861
T ₁₅ Weedy check	-	26261

Appendix-V Gross returns of individual treatments (Rs ha⁻¹)

Treatment	Doses (g ha ⁻¹)	Grain yield (kg ha ⁻¹)	Straw Yield (kg ha ⁻¹)	Gross returns (Rs. ha ⁻¹)
Pinoxaden	50	3684	7011	69307
Metsulfuron methyl	4	3156	6111	59793
Pinoxaden + carfentrazone-ethyl	50 + 20	3704	6799	68677
Pinoxaden + metsulfuron methyl	50 + 4	3836	6931	70688
Pinoxaden + 2, 4-D	50 + 500	3669	6852	68501
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	3586	7011	68201
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	3739	7116	70341
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	3519	6905	67026
Carfentrazone-ethyl	20	3066	6296	59526
Mesosulfuron + iodosulfuron	13 + 5	3386	6190	62688
Isoproturon + 2, 4-D	1250 + 500	3598	6138	64846
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	3571	6693	66772
2, 4-D	500	3046	6296	59305
Weed free	-	3862	7037	71407
Weedy check	-	2434	4866	46730

Product sale price-Rs. 11.2 kg⁻¹
 Byproduct sale price-Rs. 4 kg⁻¹

Appendix-VI Effect of weed control treatments on density (no. m⁻²) of *Phalaris minor* at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	1.8	2.8	2.9	3.4	3.6
		(2.7)	(6.7)	(8.0)	(10.7)	(12.0)
Metsulfuron methyl	4	10.7	12.4	8.4	6.8	6.3
		(114.7)	(156.0)	(70.7)	(45.3)	(40.0)
Pinoxaden + carfentrazone-ethyl	50 + 20	2.3	2.5	3.0	3.5	4.9
		(5.3)	(5.3)	(8.0)	(12.0)	(22.7)
Pinoxaden + metsulfuron methyl	50 + 4	1.8	2.1	3.3	5.0	4.7
		(2.7)	(4.0)	(10.7)	(24.0)	(21.3)
Pinoxaden + 2, 4-D	500	2.2	2.3	2.6	3.4	4.2
		(4.0)	(5.3)	(8.0)	(13.3)	(17.3)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	2.1	2.3	2.5	3.2	3.7
		(4.0)	(5.3)	(6.7)	(9.3)	(13.3)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	2.7	3.0	3.1	3.6	3.8
		(8.0)	(9.3)	(10.7)	(12.0)	(14.7)
Pinoxaden <i>fb</i> 2, 4-D	500	2.2	2.3	3.0	3.2	3.4
		(4.0)	(5.3)	(8.0)	(9.3)	(10.7)
Carfentrazone-ethyl	20	11.5	13.4	8.8	7.2	6.6
		(134.7)	(184.0)	(76.0)	(52.0)	(44.0)
Mesosulfuron + idosulfuron	13 + 5	4.8	5.8	6.1	6.0	5.6
		(24.0)	(33.3)	(36.0)	(34.7)	(30.7)
Isoproturon + 2, 4-D	1250 + 500	2.5	2.5	3.4	4.3	4.0
		(5.3)	(6.7)	(13.3)	(17.3)	(16.0)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	3.2	3.4	3.6	3.8	3.6
		(9.3)	(10.7)	(12.0)	(13.3)	(16.0)
2, 4-D	500	9.8	10.1	7.8	6.8	6.1
		(96.0)	(108.0)	(61.3)	(45.3)	(37.3)
Weed free		1.0	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		10.7	16.5	8.9	7.8	7.1
		(116.0)	(273.3)	(78.7)	(60.0)	(50.7)
LSD		1.7	2.4	1.9	1.4	1.7

Data transformed to square root transformation ($\sqrt{x + 1}$) Values given in parenthesis are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-VII Effect of weed control treatment on density (no. m⁻²) of *Avena ludoviciana* at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages				
		60	90	120	150	Harvest
Pinoxaden	50	1.0	1.0	1.9	2.1	1.8
		(0.0)	(0.0)	(4.0)	(4.0)	(2.7)
Metsulfuron methyl	4	2.2	3.4	3.8	3.4	3.2
		(6.7)	(10.7)	(13.3)	(10.7)	(9.3)
Pinoxaden + carfentrazone-ethyl	50 + 20	1.0	1.0	1.7	2.2	2.1
		(0.0)	(0.0)	(2.7)	(4.0)	(4.0)
Pinoxaden + metsulfuron methyl	50 + 4	1.0	1.0	1.8	2.2	1.4
		(0.0)	(0.0)	(2.7)	(4.0)	(1.3)
Pinoxaden + 2, 4-D	50 + 500	1.0	1.0	1.4	2.5	2.2
		(0.0)	(0.0)	(1.3)	(5.3)	(4.0)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.0	1.0	2.1	2.5	1.8
		(0.0)	(0.0)	(4.0)	(5.3)	(2.7)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.0	1.0	2.1	2.5	1.8
		(0.0)	(0.0)	(4.0)	(5.3)	(2.7)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1.0	1.0	1.8	2.2	1.7
		(0.0)	(0.0)	(2.7)	(4.0)	(2.7)
Carfentrazone-ethyl	20	2.9	3.4	3.5	3.4	3.2
		(9.3)	(10.7)	(13.3)	(10.7)	(9.3)
Mesosulfuron + idosulfuron	13 + 5	1.0	1.7	2.5	2.7	2.5
		(0.0)	(2.7)	(6.7)	(8.0)	(6.7)
Isoproturon + 2, 4-D	1250 + 500	1.7	2.3	3.4	2.8	2.5
		(2.7)	(5.3)	(10.7)	(6.7)	(5.3)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.7	2.3	2.5	3.0	2.3
		(2.7)	(5.3)	(6.7)	(8.0)	(5.3)
2, 4-D	500	4.0	4.1	4.9	3.8	3.4
		(14.7)	(16.0)	(22.7)	(13.3)	(10.7)
Weed free		1.0	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		4.1	4.7	4.9	4.3	4.0
		(16.0)	(21.3)	(22.7)	(17.3)	(14.7)
LSD		(1.3)	1.0	1.7	1.0	1.3

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parenthesis are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-VIII Effect of weed control treatment on population (no. m⁻²) of *Vicia sativa* at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	3.6	3.8	4.0	3.6	3.2
		(12.0)	(13.3)	(16.0)	(12.0)	(9.3)
Metsulfuron methyl	4	1.7	2.1	2.5	2.8	2.1
		(2.7)	(4.0)	(5.3)	(6.7)	(4.0)
Pinoxaden + carfentrazone-ethyl	50 + 20	3.2	3.4	3.6	3.2	2.5
		(9.3)	(10.7)	(12.0)	(9.3)	(6.7)
Pinoxaden + metsulfuron methyl	50 + 4	1.8	2.1	2.5	2.8	1.8
		(2.7)	(4.0)	(5.3)	(6.7)	(2.7)
Pinoxaden + 2, 4-D	50 + 500	2.1	2.3	3.4	3.8	2.5
		(4.0)	(5.3)	(10.7)	(13.3)	(5.3)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	2.8	3.2	3.4	3.9	3.2
		(6.7)	(9.3)	(10.7)	(14.7)	(9.3)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	2.2	2.3	2.3	3.7	2.5
		(4.0)	(5.3)	(5.3)	(13.3)	(5.3)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	3.0	3.6	3.6	3.8	3.0
		(8.0)	(12.0)	(12.0)	(13.3)	(8.0)
Carfentrazone-ethyl	20	2.1	2.3	2.8	3.7	2.1
		(4.0)	(5.3)	(6.7)	(13.3)	(4.0)
Mesosulfuron + idosulfuron	13 + 5	1.8	2.1	2.8	3.2	1.8
		(2.7)	(4.0)	(6.7)	(9.3)	(2.7)
Isoproturon + 2, 4-D	1250 + 500	2.1	3.0	2.9	3.4	1.7
		(4.0)	(8.0)	(9.3)	(10.7)	(2.7)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	2.5	2.5	3.7	4.0	3.0
		(5.3)	(6.7)	(13.3)	(16.0)	(8.0)
2, 4-D	500	1.7	2.3	2.5	3.0	1.7
		(2.7)	(5.3)	(5.3)	(8.0)	(2.7)
Weed free		1.0	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		3.9	3.8	4.1	3.9	3.7
		(14.7)	(13.3)	(16.0)	(14.7)	(13.3)
LSD		1.3	1.5	1.3	1.0	1.3

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parenthesis are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-IX Effect of weed control treatment on density (no. m⁻²) of *Anagallis arvensis* at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	3.5 (12.0)	7.6 (61.3)	9.1 (82.7)	9.4 (86.7)	4.7 (21.3)
Metsulfuron methyl	4	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Pinoxaden + carfentrazone-ethyl	50 + 20	1.0 (0.0)	2.9 (9.3)	3.0 (10.7)	6.1 (37.3)	3.0 (8.0)
Pinoxaden + metsulfuron methyl	50 + 4	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Pinoxaden + 2, 4-D	50 + 500	2.7 (8.0)	4.9 (24.0)	5.2 (26.7)	5.7 (32.0)	3.1 (10.7)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.0 (0.0)	2.9 (10.7)	3.4 (10.7)	4.8 (22.7)	2.8 (6.7)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	2.1 (4.0)	4.1 (21.3)	5.4 (28.0)	8.1 (73.3)	3.4 (10.7)
Carfentrazone-ethyl	20	1.0 (0.0)	1.0 (0.0)	1.8 (2.7)	2.9 (9.3)	2.1 (4.0)
Mesosulfuron + idosulfuron	13 + 5	1.9 (4.0)	2.3 (5.3)	2.2 (6.7)	3.0 (8.0)	2.2 (4.0)
Isoproturon + 2, 4-D	1250 + 500	2.5 (5.3)	2.9 (9.3)	3.8 (13.3)	4.7 (21.3)	2.7 (8.0)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.0 (0.0)	5.0 (24.0)	5.4 (28.0)	6.8 (45.3)	4.1 (16.0)
2, 4-D	500	2.1 (4.0)	2.8 (6.7)	3.4 (10.7)	4.1 (16.0)	3.0 (8.0)
Weed free		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check		4.1 (16.0)	9.8 (96.0)	9.5 (90.3)	9.5 (89.3)	5.2 (26.7)
LSD		1.3	2.3	1.6	1.9	1.4

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parenthesis are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-X Effect of weed control treatment on population (no. m⁻²) of *Lolium temulentum* at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	1.0	2.1	1.7	2.1	1.8
		(0.0)	(4.0)	(2.7)	(4.0)	(2.7)
Metsulfuron methyl	4	2.3	3.8	3.7	3.4	2.5
		(5.3)	(13.3)	(13.3)	(10.7)	(6.7)
Pinoxaden + carfentrazone-ethyl	50 + 20	1.0	2.3	1.9	1.9	1.8
		(0.0)	(5.3)	(4.0)	(4.0)	(2.7)
Pinoxaden + metsulfuron methyl	50 + 4	1.0	1.4	2.1	1.8	1.4
		(0.0)	(1.3)	(4.0)	(2.7)	(1.3)
Pinoxaden + 2, 4-D	50 + 500	1.0	2.1	2.7	2.3	1.7
		(0.0)	(4.0)	(6.7)	(5.3)	(2.7)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.0	1.7	2.7	2.5	2.3
		(0.0)	(2.7)	(8.0)	(6.7)	(5.3)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.0	2.2	2.5	1.8	1.4
		(0.0)	(4.0)	(5.3)	(2.7)	(1.3)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1.0	1.9	1.9	2.3	1.8
		(0.0)	(4.0)	(4.0)	(5.3)	(2.7)
Carfentrazone-ethyl	20	1.7	3.7	3.5	2.7	1.7
		(2.7)	(13.3)	(12.0)	(8.0)	(2.7)
Mesosulfuron + idosulfuron	13 + 5	1.0	3.4	3.2	2.5	2.3
		(0.0)	(10.7)	(9.3)	(6.7)	(5.3)
Isoproturon + 2, 4-D	1250 + 500	1.7	2.3	2.7	3.0	2.2
		(2.7)	(5.3)	(8.0)	(8.0)	(6.7)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.4	1.8	1.7	1.4	1.4
		(1.3)	(2.7)	(2.7)	(1.3)	(1.3)
2, 4-D	500	2.3	3.9	3.8	3.4	2.7
		(5.3)	(14.7)	(13.3)	(10.7)	(6.7)
Weed free		1.0	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		2.7	4.0	3.9	3.8	3.0
		(8.0)	(16.0)	(14.7)	(13.3)	(8.0)
LSD		NS	1.4	1.4	1.5	NS

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parentheses are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-XI Effect of weed control treatment on density (no. m²) of *Poa annua* at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)			
		90	120	150	Harvest
Pinoxaden	50	1.0	1.0	1.8	1.8
		(0.0)	(0.0)	(2.7)	(2.7)
Metsulfuron methyl	4	2.7	2.3	2.1	1.8
		(6.7)	(5.3)	(4.0)	(2.7)
Pinoxaden + carfentrazone-ethyl	50 + 20	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)
Pinoxaden + metsulfuron methyl	50 + 4	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)
Pinoxaden + 2, 4-D	50 + 500	1.0	1.0	1.8	1.4
		(0.0)	(0.0)	(2.7)	(1.3)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.0	1.0	2.1	1.4
		(0.0)	(0.0)	(4.0)	(1.3)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.4	1.4	1.8	1.4
		(1.3)	(1.3)	(2.7)	(1.3)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1.0	1.4	1.8	1.4
		(0.0)	(1.3)	(2.7)	(1.3)
Carfentrazone-ethyl	20	2.3	3.0	2.1	1.8
		(5.3)	(8.0)	(4.0)	(2.7)
Mesosulfuron + idosulfuron	13 + 5	1.0	1.0	1.8	2.1
		(0.0)	(0.0)	(2.7)	(4.0)
Isoproturon + 2, 4-D	1250 + 500	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.0	2.1	1.7	1.4
		(0.0)	(4.0)	(2.7)	(1.3)
2, 4-D	500	2.3	2.5	2.3	2.2
		(5.3)	(6.7)	(5.3)	(4.0)
Weed free		1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		3.8	4.1	3.2	2.5
		(13.3)	(16.0)	(9.3)	(5.3)
LSD		0.8	1.0	1.0	NS

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parentheses are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-XII Effect of weed control treatment on density (no. m⁻²) of other broad-leaf weeds at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	harvest
Pinoxaden	50	2.3 (5.3)	2.8 (9.3)	5.2 (26.7)	6.3 (40.0)	2.3 (8.0)
Metsulfuron methyl	4	1.0 (0.0)	1.7 (2.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Pinoxaden + carfentrazone-ethyl	50 + 20	1.0 (0.0)	2.3 (5.3)	3.0 (10.7)	5.0 (25.3)	1.9 (4.0)
Pinoxaden + metsulfuron methyl	50 + 4	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Pinoxaden + 2, 4-D	50 + 500	1.0 (0.0)	1.7 (2.7)	2.5 (5.3)	3.4 (13.3)	1.7 (2.7)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.0 (0.0)	1.8 (2.7)	1.7 (2.7)	4.7 (22.7)	1.4 (1.3)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.4 (1.3)	1.9 (4.0)	2.0 (5.3)	3.1 (10.7)	2.1 (4.0)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1.0 (0.0)	1.4 (1.3)	3.2 (12.0)	5.2 (28.0)	1.0 (0.0)
Carfentrazone-ethyl	20	1.0 (0.0)	2.1 (4.0)	1.4 (1.3)	3.2 (12.0)	1.0 (0.0)
Mesosulfuron + idosulfuron	13 + 5	1.0 (0.0)	1.4 (1.3)	2.2 (6.7)	1.0 (0.0)	1.4 (1.3)
Isoproturon + 2, 4-D	1250 + 500	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.0 (0.0)	1.4 (1.3)	1.4 (1.3)	5.3 (26.7)	1.7 (2.7)
2, 4-D	500	1.0 (0.0)	1.0 (0.0)	1.7 (2.7)	3.1 (12.0)	1.0 (0.0)
Weed free		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check		3.0 (8.0)	4.0 (16.0)	4.4 (18.7)	8.3 (68.0)	3.0 (8.0)
LSD		0.6	NS	2.0	2.3	NS

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parentheses are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-XIII Effect of weed control treatment on total weed count at different stages (no. m⁻²) of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	harvest
Pinoxaden	50	5.7	10.8	10.9	12.7	7.7
		(32.0)	(116.0)	(118.7)	(160.0)	(58.7)
Metsulfuron methyl	4	11.4	13.8	10.4	8.8	7.8
		(129.3)	(193.3)	(108.0)	(77.3)	(62.7)
Pinoxaden + carfentrazone-ethyl	50 + 20	3.9	6.3	6.9	9.6	7.0
		(14.7)	(38.7)	(48.0)	(92.0)	(48.0)
Pinoxaden + metsulfuron methyl	50 + 4	2.3	3.2	4.8	6.2	5.2
		(5.3)	(9.3)	(22.7)	(37.3)	(26.7)
Pinoxaden + 2, 4-D	50 + 500	3.9	6.5	7.6	9.3	6.7
		(16.0)	(41.3)	(58.7)	(85.3)	(44.0)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	3.4	5.5	6.6	9.3	6.4
		(10.7)	(30.7)	(42.7)	(85.3)	(40.0)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	3.7	4.9	5.5	6.8	5.5
		(13.3)	(24.0)	(32.0)	(46.7)	(29.3)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	4.0	6.5	8.3	11.5	6.0
		(16.0)	(44.0)	(68.0)	(136.0)	(36.0)
Carfentrazone-ethyl	20	12.2	14.8	11.0	10.5	8.1
		(150.7)	(222.7)	(120.0)	(109.3)	(66.7)
Mesosulfuron + idosulfuron	13 + 5	5.3	7.6	8.4	8.4	7.5
		(30.7)	(57.3)	(72.0)	(69.3)	(54.7)
Isoproturon + 2, 4-D	1250 + 500	4.4	5.8	7.5	8.1	6.2
		(20.0)	(34.7)	(54.7)	(65.3)	(38.7)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	4.4	7.2	8.3	10.7	7.0
		(18.7)	(50.7)	(68.0)	(113.3)	(50.7)
2, 4-D	500	11.1	12.4	11.1	10.6	8.4
		(122.7)	(156.0)	(122.7)	(110.7)	(69.3)
Weed free		1.0	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		13.3	21.2	16.0	16.5	11.3
		(178.7)	(449.2)	(257.0)	(272.0)	(126.7)
LSD		1.9	2.2	1.6	1.7	1.3

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parentheses are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-XIV Effect of weed control treatments on total weed dry matter accumulation (g m^{-2}) at different stages of observation

Treatment	Dose (g ha^{-1})	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	1.7	2.8	4.8	11.6	8.9
		(1.9)	(7.6)	(23.4)	(136.3)	(79.1)
Metsulfuron methyl	4	4.7	4.0	7.9	13.0	11.6
		(24.8)	(14.7)	(63.8)	(169.6)	(135.5)
Pinoxaden + carfentrazone-ethyl	50 + 20	1.1	1.6	3.4	6.7	7.3
		(0.2)	(1.7)	(11.3)	(44.4)	(52.9)
Pinoxaden + metsulfuron methyl	50 + 4	1.3	1.2	2.6	5.9	6.5
		(0.8)	(0.5)	(6.8)	(34.4)	(41.6)
Pinoxaden + 2, 4-D	50 + 500	1.4	1.3	3.8	5.8	6.3
		(1.0)	(0.9)	(14.6)	(37.6)	(40.3)
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.2	1.9	3.9	6.5	6.9
		(0.5)	(2.6)	(16.3)	(42.5)	(47.7)
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.4	1.2	3.3	4.0	4.6
		(1.1)	(0.5)	(11.5)	(18.6)	(23.2)
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1.2	1.4	3.0	6.5	4.0
		(0.9)	(1.0)	(8.5)	(44.7)	(16.2)
Carfentrazone-ethyl	20	3.9	4.9	9.5	12.4	11.2
		(15.6)	(24.2)	(95.1)	(155.0)	(125.4)
Mesosulfuron + idosulfuron	13 + 5	1.6	1.4	6.3	8.7	6.7
		(1.6)	(1.2)	(43.3)	(77.2)	(53.1)
Isoproturon + 2, 4-D	1250 + 500	2.2	1.2	4.9	6.3	6.7
		(3.9)	(0.5)	(23.0)	(39.6)	(44.7)
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.7	2.0	3.9	8.0	9.8
		(2.1)	(3.7)	(15.0)	(63.2)	(98.3)
2, 4-D	500	3.9	4.2	12.1	14.2	10.3
		(14.3)	(16.8)	(147.6)	(203.4)	(106.2)
Weed free		1.0	1.0	1.0	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Weedy check		3.9	5.5	10.2	15.1	13.6
		(15.8)	(31.7)	(108.1)	(228.8)	(194.8)
LSD		1.4	1.2	2.5	2.6	2.9

Data transformed to square root transformation ($\sqrt{x + 1}$), Values given in parentheses are the means of original values, DAS= Days after sowing, *fb*= followed by

Appendix-XV Effect of weed control treatments on weed growth rate (GR_w)

Treatment	Dose (g ha ⁻¹)	GR _w (g m ⁻² day ⁻¹)			
		60-90 DAS	90-120 DAS	120-150 DAS	150- harvest
Pinoxaden	50	0.188	0.528	3.763	-1.908
Metsulfuron methyl	4	0.020	1.635	3.530	-1.137
Pinoxaden + carfentrazone-ethyl	50 + 20	0.050	0.320	1.106	-0.070
Pinoxaden + metsulfuron methyl	50 + 4	-0.011	0.210	0.387	0.208
Pinoxaden + 2, 4-D	50 + 500	-0.002	0.456	0.768	-0.239
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	0.069	0.458	0.875	0.029
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	-0.017	0.366	0.395	0.054
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	0.005	0.248	1.208	-0.479
Carfentrazone-ethyl	20	0.373	2.364	1.997	-0.985
Mesosulfuron + idosulfuron	13 + 5	-0.015	1.402	1.131	-0.876
Isoproturon + 2, 4-D	1250 + 500	-0.112	0.751	0.551	0.006
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	0.054	0.374	1.608	0.603
2, 4-D	500	0.082	3.338	2.438	-2.795
Weed free		0.000	0.000	0.000	0.000
Weedy check		0.486	3.526	2.869	-0.895
LSD		0.279	0.967	1.660	NS

DAS= Days after sowing, *fb*= followed by**Appendix-XVI Effect of weed control treatments on relative growth rate of weeds (RGR_w)**

Treatment	Dose (g ha ⁻¹)	RGR _w (g g ⁻¹ day ⁻¹)			
		60-90 DAS	90-120 DAS	120-150 DAS	150- harvest
Pinoxaden	50	0.038	0.043	0.061	-0.019
Metsulfuron methyl	4	0.003	0.048	0.034	-0.008
Pinoxaden + carfentrazone-ethyl	50 + 20	0.030	0.077	0.048	0.000
Pinoxaden + metsulfuron methyl	50 + 4	-0.011	0.072	0.047	0.012
Pinoxaden + 2, 4-D	50 + 500	-0.005	0.118	0.027	0.002
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	0.056	0.054	0.041	0.000
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	-0.020	0.096	0.035	0.006
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	0.000	0.073	0.056	-0.007
Carfentrazone-ethyl	20	0.021	0.045	0.019	-0.006
Mesosulfuron + idosulfuron	13 + 5	-0.040	0.143	0.026	-0.012
Isoproturon + 2, 4-D	1250 + 500	-0.074	0.140	0.016	0.002
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	-0.004	0.077	0.050	0.008
2, 4-D	500	0.004	0.067	0.016	-0.019
Weed free		0.000	0.000	0.000	0.000
Weedy check		0.016	0.046	0.016	-0.004
LSD		NS	0.068	NS	NS

DAS= Days after sowing, *fb*= followed by

Appendix-XVII Effect of weed control treatment on weed control efficiency (%) at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	77.5	74.1	48.1	36.1	46.1
Metsulfuron methyl	4	26.8	54.8	58.1	71.9	44.6
Pinoxaden + carfentrazone-ethyl	50 + 20	92.1	91.3	80.2	65.2	48.9
Pinoxaden + metsulfuron methyl	50 + 4	93.9	97.8	90.1	86.4	72.7
Pinoxaden + 2, 4-D	50 + 500	83.9	90.6	72.3	68.9	60.3
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	90.6	92.1	79.6	69.7	59.5
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	86.6	91.7	81.2	77.5	69.4
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	84.9	90.7	69.5	52.3	65.5
Carfentrazone-ethyl	20	15.5	50.5	53.0	60.3	40.2
Mesosulfuron + idosulfuron	13 + 5	76.6	86.9	61.6	75.1	44.2
Isoproturon + 2, 4-D	1250 + 500	88.0	91.7	76.5	75.3	62.7
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	74.7	86.2	64.8	48.3	52.4
2, 4-D	500	20.3	66.1	49.2	61.1	38.1
Weed free		100.0	100.0	100.0	100.0	100.0
Weedy check		0.0	0.0	0.0	0.0	0.0
LSD		16.0	11.5	11.3	16.3	21.4

DAS= Days after sowing, *fb*= followed by

Appendix-XVIII Effect of weed control treatment on weed control index (%) at different stages of observation

Treatment	Dose (g ha ⁻¹)	Observational stages (DAS)				
		60	90	120	150	Harvest
Pinoxaden	50	91.2	81.5	84.0	40.8	65.3
Metsulfuron methyl	4	37.7	57.7	53.4	25.4	38.8
Pinoxaden + carfentrazone-ethyl	50 + 20	99.2	96.0	92.0	80.8	77.6
Pinoxaden + metsulfuron methyl	50 + 4	96.5	98.7	95.2	85.2	80.8
Pinoxaden + 2, 4-D	50 + 500	96.0	98.0	89.8	84.7	83.4
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	97.8	92.4	89.3	80.9	79.8
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	95.2	98.5	92.3	92.3	89.7
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	96.2	97.5	94.3	81.5	92.8
Carfentrazone-ethyl	20	41.9	36.1	35.8	33.3	44.1
Mesosulfuron + idosulfuron	13 + 5	92.4	96.9	71.3	66.0	79.4
Isoproturon + 2, 4-D	1250 + 500	82.9	98.5	83.6	81.4	79.7
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	91.0	90.2	89.8	70.9	58.7
2, 4-D	500	34.7	53.4	17.2	16.0	52.4
Weed free		100.0	100.0	100.0	100.0	100.0
Weedy check		0.0	0.0	0.0	0.0	0.0
LSD		21.1	16.8	21.9	17.4	19.6

DAS= Days after sowing, *fb*= followed by

Appendix-XIX Effect of different weed control treatments on crop growth rate of wheat

Treatment	Dose (g ha ⁻¹)	Crop Growth Rate (g m ⁻² day ⁻¹)				
		30-60 DAS	60-90 DAS	90-120 DAS	120-150 DAS	150- harvest
Pinoxaden	50	1.429	8.158	12.616	10.076	8.450
Metsulfuron methyl	4	0.947	5.768	12.104	9.766	8.776
Pinoxaden + carfentrazone-ethyl	50 + 20	1.625	5.859	14.713	11.339	8.372
Pinoxaden + metsulfuron methyl	50 + 4	0.851	7.690	14.089	11.832	7.762
Pinoxaden + 2, 4-D	50 + 500	1.011	7.570	13.265	10.568	8.769
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	1.005	6.397	13.341	10.035	9.881
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	1.093	8.196	13.302	11.407	7.838
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	1.106	7.849	12.243	8.864	12.412
Carfentrazone-ethyl	20	0.873	6.108	12.686	8.445	8.634
Mesosulfuron + idosulfuron	13 + 5	1.036	6.332	14.092	10.414	8.673
Isoproturon + 2, 4-D	1250 + 500	1.613	8.128	12.893	10.718	8.512
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	1.128	6.666	14.621	10.954	8.180
2, 4-D	500	1.304	5.707	11.738	9.763	8.329
Weed free		1.693	9.852	13.062	11.009	8.408
Weedy check		0.912	3.526	12.218	9.672	8.943
LSD		NS	2.996	NS	NS	NS

DAS= Days after sowing, *fb*= followed by**Appendix-XX Effect of different weed control treatments on relative growth rate of wheat**

Treatment	Dose (g ha ⁻¹)	Relative Growth Rate (g g ⁻¹ day ⁻¹)				
		30-60 DAS	60-90 DAS	90-120 DAS	120-150 DAS	150- harvest
Pinoxaden	50	0.067	0.059	0.028	0.012	0.008
Metsulfuron methyl	4	0.042	0.053	0.033	0.014	0.009
Pinoxaden + carfentrazone-ethyl	50 + 20	0.061	0.044	0.035	0.014	0.007
Pinoxaden + metsulfuron methyl	50 + 4	0.038	0.058	0.031	0.014	0.007
Pinoxaden + 2, 4-D	50 + 500	0.044	0.054	0.030	0.013	0.008
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	0.043	0.052	0.032	0.013	0.009
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	0.059	0.056	0.028	0.013	0.007
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	0.034	0.056	0.029	0.011	0.011
Carfentrazone-ethyl	20	0.046	0.052	0.032	0.012	0.009
Mesosulfuron + idosulfuron	13 + 5	0.053	0.053	0.036	0.013	0.008
Isoproturon + 2, 4-D	1250 + 500	0.064	0.055	0.028	0.013	0.008
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	0.044	0.051	0.035	0.014	0.007
2, 4-D	500	0.050	0.048	0.032	0.014	0.008
Weed free		0.043	0.053	0.024	0.012	0.007
Weedy check		0.066	0.046	0.043	0.015	0.010
LSD		0.018	NS	NS	NS	NS

DAS= Days after sowing, *fb*= followed by

Appendix-XXI Effect of weed control treatment on total crop dry matter accumulation (g m^{-2}) at different stages of observation

Treatment	Dose (g ha^{-1})	Observational stages (DAS)					
		30	60	90	120	150	Harvest
Pinoxaden	50	7.2	50.9	295.6	674.1	916.3	1073.8
Metsulfuron methyl	4	13.0	44.2	217.2	580.4	798.9	929.4
Pinoxaden + carfentrazone-ethyl	50 + 20	10.8	65.8	241.6	683.0	896.6	1051.0
Pinoxaden + metsulfuron methyl	50 + 4	17.0	50.9	281.6	704.2	929.1	1078.0
Pinoxaden + 2, 4-D	50 + 500	15.2	57.3	284.4	682.3	903.6	1056.4
Pinoxaden <i>fb</i> carfentrazone-ethyl	50 <i>fb</i> 20	15.3	53.6	245.5	645.7	912.7	1062.0
Pinoxaden <i>fb</i> metsulfuron methyl	50 <i>fb</i> 4	9.9	59.4	305.3	704.3	943.4	1088.4
Pinoxaden <i>fb</i> 2, 4-D	50 <i>fb</i> 500	18.4	52.5	287.9	655.2	921.2	1052.3
Carfentrazone-ethyl	20	12.7	50.1	233.3	613.9	837.7	942.9
Mesosulfuron + idosulfuron	13 + 5	9.7	46.0	236.0	658.7	860.4	963.5
Isoproturon + 2, 4-D	1250 + 500	10.2	57.9	301.7	688.5	899.5	994.4
Clodinafop <i>fb</i> 2, 4-D	60 <i>fb</i> 1000	14.0	49.8	249.8	688.4	910.1	1036.4
2, 4-D	500	12.9	52.8	224.0	576.1	811.8	938.9
Weed free		21.1	76.8	372.4	764.3	953.4	1095.8
Weedy check		4.8	34.8	140.6	468.7	625.8	715.5
LSD		7.6	19.1	98.3	120.5	51.6	34.2

DAS= Days after sowing, *fb*= followed by

Appendix-XXII Layout of ANOVA table

Source of Variation	Degree of freedom
Treatment	14
Replication	2
Error	28
Total	44

Brief Biodata of student

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Father's Name : Sh. Shyam Bihari Katara
Mother's Name : Smt. Usha Katara
Date of Birth : 5 Nov. 1988
Permanent Address : House No. 9, Court Road, Alwar, Rajasthan

Academic Qualifications:

Qualification	Month	Year	School/Board/ University	Marks (%)	Division
10 th	June	2003	Board of secondary education, Ajmer	77.50	Ist
10+2	June	2005	Board of secondary education, Ajmer	74.77	Ist
B.Sc. Agriculture	June	2010	SKUAST-Jammu	76.90	Ist

Fellow/Scholarship/Gold Medals/Awards/Any Other Distinction:
Junior Research Fellowship

Publications:

Total: Nil
Research papers (in peered journals): - Nil
Scientific Popular Articles: - Nil
Others: Nil