

**INTEGRATED WEED MANAGEMENT IN *KHARIF*
SORGHUM (*Sorghum bicolor* (L.) Moench)**

**Thesis submitted to the
University of Agricultural Sciences, Dharwad
in partial fulfillment of the requirements for the
Degree of**

MASTER OF SCIENCE (AGRICULTURE)

IN

AGRONOMY

BY

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1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the important cereal crops globally after wheat, maize, rice and barley. Sorghum is an unique crop among the major cereals and the staple food and fodder crop of the world's poor and most food-insecure populations, located primarily in the semi-arid tropics. During 2010–11, world sorghum grain production was about 55.7 million tonnes with an area and productivity of 40.6 million ha and 729 kg ha⁻¹ respectively (Anon., 2012a). Sorghum is one of the major cereal crops consumed in India after rice and wheat. In India the area and production of sorghum during 2010-2011 was 7.06 million ha and 6.74 million tonnes respectively with productivity of 1047 kg ha⁻¹ (Anon., 2012b). The crop is primarily produced in Maharashtra, Andhra Pradesh and Northern districts of Karnataka. These three states together account for 80% of the all-India production (Parthasarathy Rao, 2010). India is the largest producer of sorghum in the world followed by Mexico and Nigeria. During 2010-11 sorghum grain production of Karnataka state was 1.41 million tonnes with an area and productivity of 1.37 million ha and 1029 kg ha⁻¹, respectively (Anon., 2012b).

In Karnataka, sorghum is mainly grown in Belgaum, Bijapur, Bagalkot, Dharwad, Haveri and Gadag districts both in *kharif* and *rabi* seasons. Karnataka is the second largest sorghum producer in India, after Maharashtra. Sorghum is the most important crop of Karnataka in terms of area, accounting for about 36 per cent of the total area under food crops, followed by paddy (24.3 per cent), finger millet (18.1 per cent), maize (7.9 per cent) and pearl millet (7.5 per cent). Use of high yielding varieties/hybrids, fertilizer management, weed management, irrigation management, plant protection etc. are the important factors responsible for increasing the sorghum productivity.

The major sorghum growing area (about 68%) is under *rabi* season as compared to *kharif* season in Karnataka. Weeds are one of the major problems in limiting the productivity of *kharif* sorghum. Weed competition in grain sorghum reduces yields, causes harvesting losses and increases seed content of the soil seed bank. Weed infestations in the early growing season will reduce yields significantly. Grain sorghum seedlings grow slowly and are weak competitors to most of the weeds. Research data have shown that one pigweed plant per 3 foot of row left uncontrolled until sorghum reaches the three-leaf stage will reduce yields by 10 per cent. Heavy infestations of grassy weeds may cause up to a 20 per cent yield reduction in the first two weeks after sorghum germination. Late season weed infestations have lesser effect on sorghum yield, but reduce harvesting efficiency and may reduce harvested yields.

Weeds emerge fast and grow rapidly competing with the crop severely for growth resources *viz.*, nutrients, moisture, sunlight and space during entire vegetative and early reproductive stages of sorghum. They also transpire lot of valuable conserved moisture and absorb large quantities of nutrients from the soil. Further, wide space provided to the sorghum, allows fast growth of variety of weed species causing a considerable reduction in yield by affecting the growth and yield components. Presence of weeds reduces the photosynthetic efficiency, dry matter production and distribution to economical parts and thereby reduces sink capacity of crop resulting in poor grain yield. Thus, the extent of reduction of yield losses ranging from 40% to 80% had been attributed to weed competition during the growth of the sorghum (Lagoke *et al.*, 1990). Mishra (1997) reported 15-40 per cent loss in grain yield due to weed competition in sorghum. It is well established that 30 to 60 DAS is the most critical period for crop-weed competition in sorghum. Hence, managing weeds during this period is most critical for getting higher yields. Clean and weed free cultivation is, therefore one of the principles of modern day farming agriculture.

Based on survey conducted in the *kharif* sorghum growing areas of Northern transitional zone of Karnataka, the sorghum production suffers greatly due to weed problem, which offers limitations to crop. It was found that weed infestation become unmanageable throughout the growing period by the traditional methods of interculturing and manual weeding due to continuous and heavy rains during entire vegetative and early reproductive stages of *kharif* sorghum. Though these methods are more effective in controlling weeds in medium to low rainfall areas, they are tedious and time consuming besides labour intensive and costly. Often these operations are difficult to carry out in the field owing to excess soil

moisture due to heavy and continuous *kharif* rains. Under such situations weed control becomes very difficult either by hand weeding or by intercultivation. The problem is further aggravated because of severe labour scarcity to control weeds effectively at required time. However, chemical weed management has become efficient, time saving and cheaper with herbicides. With the introduction of herbicides this is particularly true under intensive crop production practices with high yielding varieties which demand greater amounts of fertilizer and water, which are also conducive to greater weed growth.

The choice of any weed control measures therefore, depends largely on its effectiveness and economics. Because of increased cost and non availability of labours in required quantity for hand weeding, herbicides not only control the weeds timely and effectively but also offer a great scope for minimizing the cost of weed control irrespective of situations. Use of pre-emergent and post-emergent herbicides would make the herbicidal weed control more acceptable to farmers, which will not change the existing agronomic practices but will allow for effective management of weeds. Usage of pre-emergence herbicides assumes greater importance in the view of their effectiveness from initial stages. As the weeds interfere during the harvesting of the crop, post-emergence herbicides at about 35 DAS may help in avoiding the problem of weeds at later stages. Under such situation, managing weeds through pre-emergence, post-emergence and sequential use of herbicides will be an ideal means of controlling the weeds for enhancing productivity of *kharif* sorghum.

Keeping the above information in view, an investigation was carried out to study the integrated weed management in *kharif* season sorghum in Northern transitional zone of Karnataka during *kharif* season with the following objectives:

1. To study the effect of integrated weed management practices on weed flora of *kharif* sorghum.
2. To study the effect of integrated weed management practices on growth and yield of *kharif* sorghum and
3. To work out the economics of different integrated weed management practices.

2. REVIEW OF LITERATURE

Sorghum is the major cereal grain crop cultivated in arid and semi arid tropics of the world. The crop yields are very low in these tracts owing to vagaries of monsoon and other factors which include fertilizers, irrigation, pest and diseases, weeds etc. Weeds compete severely for growth resources viz., light, nutrients, moisture and space during entire vegetative and early reproductive growth stages of *kharif* sorghum resulting in lower crop yield. It was reported that loss of sorghum yield due to weeds is to the extent of 15 to 40 per cent (Mishra, 1997). During *kharif* season due to heavy and continuous rains and scarcity of labour, it is very difficult to manage the weeds by conventional cultural/mechanical methods. Therefore, the study of chemical weed control assumes a greater importance in the cultivation of *kharif* sorghum. The literature on weed flora, crop weed competition and its effect on growth, yield and yield components of *kharif* sorghum and weed control through the pre-emergence, post-emergence application of herbicides and economics are reviewed in this chapter.

2.1 Weed spectrum associated with sorghum

The weed flora differs widely with the environment, soil conditions and cropping pattern. Generally, weeds are found in large numbers with greater vigour, because of their wider adaptability even under extremities of climatic, edaphic and biotic stresses. High persistence nature of weeds is attributed to their ability of high seed production and longer seed viability.

Murthy (1950) listed 57 weed species in sorghum grown under black clay loam soils of Karnataka. Krishnasastry (1957) had reported about 203 weed species which were commonly found in cultivated fields of Karnataka state. At Nagpur, Vaidya (1959) noticed about 21 weed species in an experiment on weed control in sorghum. Verma and Bharadwaj (1963) had mentioned that *Striga lutea*, *Sorghum halepense* and *Cyperus rotundus* were most obnoxious weeds in sorghum field. Mahendra Singh *et al.* (1973) observed *Trianthema monogyna* as predominant weed followed by *Digera arvensis*, *Cyperus rotundus* and *Cynodon dactylon* till harvest of grain sorghum.

Shetty (1979) observed *Cyperus rotundus*, *Cynodon dactylon* and *Striga spp.*, apart from annual grasses and broad leaved weeds in sorghum field under the tropical areas. Upadhyay *et al.* (1981) noticed, monocot weeds like *Cynodon dactylon*, *Cyperus rotundus*, *Dinebra spp.*, *Cana indica*, *Commelina benghalensis*, and dicot weeds like *Striga densiflora*, *Abutilon indicum*, *Euphorbia spp.*, *Achyranthus aspera*, *Phyllanthus niruri*, *Corchorus acutangulus*, *Bidens pilosa* and *Convolvus arvensis* in sorghum field.

Sharanappa (1980) observed 10 monocots and 29 dicot weeds in *kharif* sorghum grown in black soil of Dharwad. Common weeds found in sorghum fields in Punjab were *Cucumis melo*, *Sorghum halepense* and *Celosia argentea* (Sharma *et al.*, 1981) and *Dinebra retroflexa*, *Ischaemum pilosum*, *Digera arvensis* and *Amaranthus viridis* in Maharashtra (Latchanna, 1983). Verma and Katyal (1989) reported *Trianthema portulacastrum* Linn., *Echinochloa colona* (L.) Link, *Cyperus rotundus* (L.), *Digera arvensis* Fork, and *Dactyloctenium aegypticum* (L.) Richter as the dominant weed species to the extent more than 70% of the weed flora in the pearl millet experimental field.

Solaiappan *et al.* (1992) noticed major weed species in sorghum experimental field were *Boerhaavia diffusa* L., *Celosia argentea* L., *Phyllanthus maderaspatensis*, *Tridax procumbens* L., *Trifolium spp.*, *Sorghum halepense* (L.) Pers., *Dactyloctenium aegypticum* (L.) Willd. and *Cynodon dactylon* (L.) Pers. In general though diverse weed species were reported in maize crop, some weed species are consistently reported over space and time in maize ecosystem. They were *Digitaria spp.*, *Amaranthus retroflexus* and *Amaranthus viridis* (Sharma and Nayital, 1993), *Echinochloa colonum* (Shad *et al.*, 1993).

Rout and Satapathy (1996) reported that in sandy loam (Alfisols) soils of Umerkote (OUAT), the major weed species present under rainfed maize were *Cynodon dactylon*, *Digitaria setigera*, *Digitaria ciliaris*, *Leptochloa chinensis*, *Dactyloctenium aegypticum*, *Eleusine indica*, *Cyperus rotundus*, *Cyperus iria*, *Celosia argentea*, *Commelina benghalensis*, *Sida acuta*, *Aeschynomene indica* and *Acanthospermum hispidum*.

Sandhu *et al.* (1996) reported that presence of 75 weed species in maize crop fields in Punjab and the predominant weeds associated with the crop were *Eleusine aegypticum*, *Eragrostis tenella*, *Leptochloa panacea*, *Trianthema portulacastrum*, *Digera arvensis* and *Cyperus rotundus*.

Grassy weeds like *Echinochloa colonum* and *Echinochloa crus-galli*, sedges like *Cyperus iria* and *Cyperus esculentus* and broad-leaved weeds like *Commelina benghalensis* and *Ageratum conyzoides* constituted more than 90 per cent of weed flora in maize (Saini and Angiras, 1998). Sharma *et al.* (2000b) reported that in Udaipur (Rajasthan) the predominant weeds were observed in sorghum crop were *Commelina benghalensis* L., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Digera arvensis* Forsk., *Echinochloa colonum* (L.) Link., *Eclipta alba* (L.) Hassk., *Phyllanthus niruri* Hookf., *Solanum nigrum* L., *Sorghum halepense* (L.) Pers. and *Trianthema portulacastrum* L.

It was observed that maize cultivation in *kharif* season was dominated by weeds like *Chenopodium album*, *Chenopodium murale*, *Anagallis arvensis*, *Melilotus indica*, *Euphorbia hirta* and *Convolvulus arvensis* (Porwal, 2000). Predominant weed species in *kharif* maize comprised of grasses (85.0-90.4 %) such as *Echinochloa crusgalli*, *Eleusine indica*, *Digitaria sanguinalis* and *Cynodon dactylon*, broad leaved weed species (8.4 to 13.1%) such as *Commelina benghalensis*, *Amaranthus viridis*, *Cucumis celosus* and sedges (1.2-1.9 %) such as *Cyperus rotundus* (Sharma *et al.*, 2000a).

Pandey *et al.* (2000) at Almora observed that the dominant weeds species in maize were, *Echinochloa colonum*, *Bracharia ramosa*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Eleusine indica*, *Setaria glauca*, *Sorghum halepense* and *Panicum spp.* among the grassy weeds, *Ageratum conyzoides*, *Galinoga parviflora*, *Commelina benghalensis*, *Lindernia ciliate*, *Polygonum hydropiper*, *Euphorbia geniculata* and *Oxalis latifolia* among the broad leaved weeds and *Cyperus rotundus* among sedges.

Soundari and Kathiresan (2002) reported that weed flora like *Trianthema portulacastrum* L., *Eclipta alba* L., *Cyperus rotundus* L. and *Cynodon dactylon* (L.) Pers were observed in sorghum experimental field. The maize experimental field was infested with *Amaranthus spinosus*, *Commelina benghalensis*, *Cynodon dactylon*, *Cyperus rotundus*, *Digera muricata*, *Echinochloa colonum*, *Parthenium hysterophorus* and *Trianthema portulacastrum* (Mundra *et al.*, 2003). Sinha *et al.* (2003) in North Bihar reported that *Cyperus rotundus*, *Cynodon dactylon*, *Sorghum halepense*, *Chenopodium album*, *Convolvulus arvensis*, *Anagallis arvensis*, *Cannabis sativa* and *Melilotus alba* as important weed flora during winter season in maize crop.

Kamble *et al.* (2005) found the major weed flora in the maize field comprised of *Digera arvensis*, *Celosia argentea*, *Euphorbia hirta*, *Lagasca mollis*, *Parthenium hysterophorus* as broad leaf weeds and *Cyperus rotundus*, *Cynodon dactylon* *Dinebra Arabica* as narrow leaf grassy weeds. The major weeds found in the experimental field of rainfed maize were *Digera arvensis*, *Trianthema portulacastrum*, *Amaranthus viridis*, *Cynodon dactylon* and *Cyperus rotundus* (Ramesh and Nadanassababdy, 2005). Patel *et al.* (2006) observed the major weed flora viz., *Eleusine indica*, *Digitaria sanguinalis*, *Eragrostis major* and *Dactyloctenium aegyptium* as monocot weeds and *Digera arvensis*, *Phyllanthus niruri*, *Boerhavia diffusa* and *Euphorbia hirta* as dicot weeds in the experimental plots of *kharif* maize.

Rao *et al.* (2007) reported that dominating weeds in sorghum were *Digera muricata* (L.) Mart. Syn. *Digera arvensis* Forsk., *Amaranthus spinosus* L., *Amaranthus viridis* L., *Trianthema portulacastrum* L., *Euphorbia hirta* L., *Tribulus terrestris* L. among the broad-leaf weeds; *Setaria glauca* L., *Digitaria sanguinalis* (L.) Scop. *Dactyloctenium aegyptium* (L.) Willd. and *Panicum repens* L. among the grassy weeds; and *Cyperus rotundus* L (Sedges). Among them, *D. arvensis*, *A. spinosus* and *A. viridis* were the most predominant weed species with the average density of 30, 25 and 15%, respectively.

Chopra and Angiras (2008) found major weed flora in maize experimental plot comprised of *Digitaria sanguinalis* (38.08%) of the total weed flora and other important weeds were *Echinochloa colona* followed by *Panicum dichotomiflorum*, *Commelina benghalensis*, *Cyperus iria*, *Brachiaria ramosa*, *Oxalis latifolia*, *Ageratum conyzoides*, *Cynodon dactylon*, *Ipomea purpurea* and *Polygonum alatum*.

Sharma and Gautam (2003) observed *Cynodon dactylon* L. (21%), *Cyperus rotundus* L. (15%), *Echinochloa crusgalli* L. (12%), *Echinochloa colonam* L. (13%), *Agropyron repens* L. (11%), *Digitaria sanguinalis* L. (8%), *Eclipta alba* L. (5%), *Euphorbia hirta* L. (4%) and *Commelina benghalensis* L. (2%) as dominant weed flora in maize field.

2.2 Yield losses caused by weeds in sorghum

Sorghum competes poorly with weeds during the early growth period. Burnside (1967) noticed about 80 per cent reduction in sorghum yield due to weeds for the first three weeks. Mani *et al.*, (1968) estimated about 6, 30 and 40 per cent losses in grain yields of sorghum at Jodhpur, Delhi and Nagpur, respectively.

Kuspe *et al.* (1968) reported about 37.4 per cent grain yield reduction in sorghum (CSH-1) due to weeds. In Texas High Plains (USA), one pigweed for every 120 ft area in sorghum spaced at 40 inch row reduced the yield by 5 per cent and also one pigweed for every 32, 8, 2 and 1 ft sorghum row reduced yield to the extent of 10, 20, 36 and 48 per cent, respectively (Wiese and Shiply, 1969).

The weed competition in weedy check treatment reduced grain yield of sorghum by 29 per cent as compared to weed-free treatment and by 24 per cent compared with interrow cultivation treatment (Thomas *et al.*, 1980). According to Pamplona and Madrid (1979), the common practice of interrow cultivation leaves weeds in the row which reduced the sorghum yield by 28 per cent.

Wiese *et al.* (1983) reported that the loss in sorghum grain yield was 34 per cent from pigweed (*Amaranthus spp.*) infestation, 31 per cent from *Echinochloa crus-galli* and other annual grasses and 48 per cent from *Sorghum halepense*. Yields were less affected by weeds where soil moisture content was high but in dry year, yield loss was up to 96 per cent. When climatic conditions were extreme, losses averaged upto 35 per cent (Lopez and Galetto, 1983). Weeds cause heavy losses to *kharif* sorghum.

2.3 Nature of crop-weed competition

The degree of crop weed competition is determined by the weed species and their density, duration of infestation, associated crop in the field, growth habit of crop plants and environmental condition. Weed that grow with crop deplete considerable amount of costly fertilizer nutrients, moisture, light and space, thereby resulting poor growth and lower yield.

2.3.1 Competition for moisture

Moisture is the sole limiting factor in crop production under rainfed conditions. The weed in association with crops will also compete for moisture. Robbins *et al.* (1942) stated that the water requirement of *Amaranthus spp.* was about 3 times that of millets and the requirement of *Chenopodium album* was twice that of sorghum. According to Nijhawan (1944), it was possible to save 750 to 1250 tonnes of water per ha up to six feet depth by keeping the soil free from weeds under dry farming conditions. Under dry farming conditions at Sholapur, the transpiration coefficient obtained for different weeds was 556 for *Tephrosia purpurea*, 1402 for *Tridax procumbens*, while it was only 327 for sorghum (Kanitkar *et al.*, 1960).

Pathak (1958) reported that the soil moisture level at 18 inch depth was higher in the uncultivated land followed by weed free plot (19.8%) and 2,4-D sprayed plot (18.9%), while it was minimum in cultivated plot in corn crop. According to Arakeri *et al.* (1962), the crop yield could be increased by 10 to 15 per cent by avoiding transpiration through weeds. The weeds absorbed more moisture than the crop and affected its yield (Kondap and Bathkal, 1981).

2.3.2 Competition for nutrients

Weeds are the potential competitors for nutrients and they deplete the nutrients from different soil layers. According to Vengaris *et al.* (1953) weeds were important competitors with cultivated plants for nitrogen and potash. Weeds in general and dicots in particular, have high content of minerals and proteins. They are able to accumulate about as much of calcium and magnesium as legumes and as large amount of potash as grasses.

Klingman (1961) stated that weeds accumulate twice the amount of nitrogen, 7.6 times of magnesium as that of corn plant. For every unit of 4.5, 1.5 and 4.0 kg NPK removed by weeds, there was a corresponding reduction of 100 kg grain yield of sorghum and the removal of nutrients by the weeds was at faster rate than the crop (Sankaran and Mani, 1972).

The weeds removed 26 kg N, 7 kg P₂O₅ and 42 kg K₂O per ha upto 40 days from the hybrid sorghum (Badhe and Nalamwar, 1981). According to Jayakumar *et al.* (1987), uptake of N, P and K by weeds was about 14 to 38, 2 to 10 and 16 to 44 kg per ha, respectively in sorghum.

2.3.3 Competition for light

Light is a prime factor around which competitive factors develop. Under a thick canopy, light is the sole limiting factor for weed growth. In the absence of light, the competition for moisture and nutrients is greatly reduced. On the contrary, when moisture and nutrients are adequate, then the competition is mostly for light (Stahler, 1948).

Sweet *et al.* (1974) observed perfect correlation between light interception and shading and weed suppression. Further, the author has also reported that dry matter production of *Portulaca oleracea*, *Ipomea triloba*, *Digitaria sanguinalis*, *Eleusine indica*, and *Cyperus rotundus* under 50 per cent shade was reduced by 75, 46, 56, 60 and 52 per cent, respectively.

2.4 Critical period of crop-weed competition

Determination of the most critical period of crop-weed competition for nutrients, moisture, light and space is of greater importance to make weed management practices more effective and economical and thereby increasing crop yield. Various workers have established the critical period of crop weed competition in sorghum.

Rao and Kondap (1977) found that the critical period of weed competition in sole sorghum found to be 30 to 45 days after sowing. According to Shetty (1979), the critical period of sorghum for weed competition was the first 30 to 40 days of growth. The most critical period of crop weed competition was between 15 and 30 days after sowing when the yield was 76 to 82 percent of weed free period till harvest. Dry matter production of weed was several times higher than that of crop upto 60 days but later a reverse trend was observed (Kondap and Bathkal, 1981).

Shad *et al.* (1993) reported that, at Islamabad, in maize critical period of crop weed competition was found in between 3 and 5 weeks after sowing. Tygai *et al.* (1993) reported that rainy season maize requires a weed free environment for 15-45 days after sowing to produce yields on par with season long weed free plots.

Carey and Kells (1995) suggested that appropriate timing of weed control in maize is when weeds grow 10 cm tall, after which, yields reduced even though weeding was completed. Recent experimental results showed that the critical period of crop weed competition was recorded between 3 and 6.5 weeks after corn emergence, where the field was severely infested with *Sorghum halepense* (Ghosheh *et al.*, 1996).

Hamill and Zhang (1997) concluded that bentazon/atrazine (1.6 kg ha⁻¹) along with adjuvant (1 litre ha⁻¹) gave significant control of broad leaved weed in maize crop. Tapia *et al.* (1997) observed that corn yield was higher when grassy weeds were controlled at 10 cm of height by post-emergence nicosulfuron (35 g ha⁻¹) in comparison to standard pre-emergent herbicides. The weedy environment beyond 30 days and upto 45 days after sowing was detrimental to maize growth and caused yield loss (Porwal, 2000).

Critical stage of crop weed competition in maize was 30 to 45 days after sowing (Kamble *et al.* 2005). Sohrab and Ali (2009) reported the critical period of crop-weed competition of corn was from 5 to 15 leaf stage (19-55 DAE) to prevent yield losses of five per cent.

From all experimental results, it may be inferred that the loss of grain yield of sorghum can be minimized and the maximum water use efficiency and nutrients use efficiency of sorghum can be enhanced by controlling the weed dominance during first 30 to 45 days after sowing,

2.4.1 Effect of crop-weed competition

Kharif Sorghum is the one of the most sensitive crop to weed competition and losses of grain yield are also reported. Competition between crop and weed is most severe when the competing plants have similar vegetative habits and demand for same resources. A brief review of literature on the effect of crop-weed competition in *kharif* sorghum is given below.

2.4.2 Effect on growth and yield components

A field experiment in Delhi to assess the economics of weed control in winter maize revealed that maximum grain yield of 7140 kg ha⁻¹ achieved with post-emergence application of atrazine @ 0.25 kg ha⁻¹ at knee high and tasseling stage (Dixit, 1995). Thakur and Sharma (1996) highlighted that atrazine (1.25 kg ha⁻¹) and hand weeding (20 and 40 DAS) were on par with each other and resulted in significantly higher grain yield of rainfed maize, test weight, and grain weight per cob followed by atrazine @ 0.75 kg ha⁻¹ with one hand weeding at 20 DAS.

Atrazine @ 2.0 kg ha⁻¹ being on par with atrazine @ 1.5 kg ha⁻¹ recorded significantly more number of cobs, cob length, grains /cob and grain yield of maize as compared to atrazine @ 1.0 kg ha⁻¹, Saini (2000). Shinde *et al.* (2001) proved that the weed free check had the higher plant height, number of leaves plant⁻¹, dry matter plant⁻¹ at harvest and grain yield of maize and was on par with pre-emergence application of atrazine @ 1.0 kg ha⁻¹.

Shekhawat and Gautam (2002) reported the higher values of growth parameters in weed free check, followed by two hand weedings or atrazine @ 1.0 kg ha⁻¹ compared to the untreated control in maize crop. Among atrazine treatments, atrazine applied at 1.0 kg ha⁻¹ as spray between the rows recorded maximum plant height, cob weight and shelling per centage in over the atrazine sprayed as blanket spray in maize crop (Sharma and Gautam, 2003)

Deshmukh *et al.* (2008) reported that the application of atrazine @ 0.75 kg ha⁻¹ as a pre-emergent followed by one hand weeding at 45 DAS was at par with weed free check and application of atrazine @ 1 kg ha⁻¹ recorded significantly higher grain, fodder and maize equivalent yield over rest of the weed control treatments. The above findings are similar to the results obtained by Khot and Umrani (1992), Pardkar and Sharma (1993) and Mundra *et al.* (2003) in maize crop.

2.5 Weed control methods and their effect on crop growth and yield attributes

The review on the weed flora revealed that weeds growing in association with sorghum crops are of wide range and intensity, varying in their growth habit and life cycles. Therefore, no single weed control method gives continuous and effective weed control.

2.5.1 Manual method of weed control

The cultural methods of weeding are most common methods of weed control. Although herbicides are replacing the traditional methods, at faster rate cultural methods of weed control are still practiced in India. Though weed control methods like manual weeding and hoeing are possible, sometimes they are not effective due to unavailability of labours and incessant rains. Hence chemical method of weed control provides better control of weeds.

Ishag (1968) observed that under irrigated conditions in Sudan, two hand weedings reduced the growth of many weeds except striga. Witch population was increased probably because of the subterranean plants and due to the lessened competition from other weeds in sorghum crop. Robinson *et al.* (1967) opined that witchweed could be controlled by adopting five year rotation of maize, cotton, soybean, groundnut and sorghum.

Traditional method (3 hand weedings and 3 hoeings) of weed control practiced by cultivators gave higher grain yield of sorghum (Gupta and Singh, 1967) as compared to use of herbicides (Bathkal *et al.*, 1969).

Experimental results, conducted on clay-loam soil of Chittorgarh showed that hand weeding significantly reduced the density and dry matter of weeds in maize compared to chemical treatment, because chemicals were able to control weed growth up to 30 days after which their efficacy decreased (Intodia *et al.*, 1996).

Sharma *et al.* (2000a) observed that hoeing at 15 DAS controlled growth of all species and their population at 30 DAS was less than half (23.32 weeds per m²) compared with no interculture (67 to 70 weeds per m²) in rainfed maize.

Maximum weed control efficiency was observed in hand weeding (91.9%) in maize by Sinha *et al.* (2003).

Kolage *et al.* (2004) reported that lower weed intensity was observed with two hand weedings at 20 and 40 DAS in maize crop. The pooled data of 3 years revealed that 2 hoeings + 2 hand weedings at 20 and 40 DAS recorded substantially higher grain (69.29 q ha⁻¹) and fodder (103.61 q ha⁻¹) yields of hybrid maize over the rest of the treatments, but was found at par with pre-emergence application of atrazine + one hoeing + one hand weeding at 20 DAS (Kamble *et al.*, 2005).

Tripathi *et al.* (2005) reported that manual weeding twice at 15 and 30 DAS registered 22.2, 17.6, 22.0 and 20.3 per cent reduction in *Cyperus rotundus*, *Digera arvensis*, *Phyllanthus niruri* and *Commelina benghalensis* population and also heavy decline in weed dry weight (87.8% WCE) in maize. In another trail Hand weeding twice at 3 and 6 weeks after sowing in maize crop showed significant effect in reducing weeds and also increased the yield when compared with weedy check. (Nagalakshmi *et al.*, 2006)

2.5.2 Chemical method of weed control

Use of herbicides hold a good promise for timely, effective and efficient weed control in areas where labour is scarce and expensive, Since most of weeds emerge either before or along with the crop, the use of pre-sowing incorporation or pre-emergence herbicides is a better management practice. The choice of herbicides for a particular situation will depend upon the climate, soil type, prevalent weed species, crop cultivar and method of propagation and management.

2.5.2.1 Pre-emergence application of herbicides

Pre-emergence herbicides control grassy and broad leaved weeds in any tropical cereals. Their use would be appropriate not only for minimizing early weed competition, but also for reducing the work load during the peak labour period (Baker and Terry, 1991).

2.5.2.1.1 Pre-emergence application of atrazine

Atrazine belongs to the heterocyclic nitrogen compounds and comes under triazines. It is a soil and leaf herbicide. The triazines move in the transpiration stream mostly in the apoplast of treated plants and inhibit photosynthetic electron transport (Baker and Terry, 1991).

Jones (1955) obtained adequate control of witchweed with the application of MCPA or 2,4-D shortly after sowing sorghum. Delayed applications resulted in reducing the growth of only aerial portion preventing the setting up of seeds. Rahudkar (1959) obtained an effective control of weeds in local sorghum with 0.2 per cent aqueous solution of 2,4-D as pre-emergence spray. All dicot and two grass weeds viz., *Eragrostis plumose* and *Panicum isachne* were effectively controlled, while there was no effect on *Cynodon dactylon* and *Cyperus rotundus*.

Burnside and Wicks (1965) obtained increased grain yields, bushel weight, 1000 grain weight, height at maturity and decreased weed yield as compared to unweeded check when atrazine was sprayed as pre-emergence spray to sorghum hybrid RS-610 at Lincoln and North Platte (USA). Burnside (1966) suggested use of more effective pre-emergence herbicides with narrow spacing at Lincoln and Nebraska for sorghum production with cultivation practice. Best control of *Digitaria spp.* And *Amaranthus hydrides* was obtained with atrazine and norea at 1.3 or 1.7 kg per ha as pre-emergence spray without injuring the crop.

Pre-emergence spray of atrazine or propazine at 1.5 kg per ha gave an effective and selective control of annual grasses and non-grass weeds for the first 6-8 weeks of sowing and gave the maximum grain yield at Delhi (Mani and Chandhokar, 1965). Hosmani *et al.* (1969) reported that atrazine @ 2 kg per ha effectively controlled the weeds in S-413 sorghum at Dharwar. The monocot weed population was reported to be minimum @ 2 kg per ha in atrazine and weeded plots. Pre-emergence application of simazine @ 0.25 and 0.5 kg per ha reduced the dry weight of annual weeds significantly over unsprayed plots. *Cynodon dactylon* was proved to be most tolerant to simazine as it spreads more freely after 30 days of spray.

In a study carried out at Nagpur (Mehlotra *et al.*, 1968), indicated the better control of the prominent weeds such as *Trianthema monogyna*, *Phyllanthus niruri*, *Panicum colonum* and *Cyperus rotundus* in sorghum with cotoron followed by atrazine and prometryne as pre-emergence spray. Cotoron and atrazine gave 92 and 89 per cent increased grain yield, respectively, over control. Atrazine has been found to be an effective herbicides for control of annual grasses and broad leaved weeds in sorghum (Burnside and Wicks, 1964 and Robinson *et al.*, 1964). Lyubenov (1969) reported effective control of annual weeds with atrazine (50%), propazine (50%) and prometryne (50%) at 4-5 kg per ha.

Krishnamurthy (1970) reported that 2,4-D @ 1.0 kg per ha reduced sorghum population (60-61%) when compared to simazine (70-73%) though the weed population was same in both cases. He further noticed an increased sorghum grain yield of 1072 and 996 kg per ha over control (869 kg/ha) with the application of atrazine (2.5 kg/ha) and simazine (1.25 kg/ha), respectively. Weed count was low in herbicide treated plots

In Nigeria, atrazine has not caused injury to sorghum even when applied at rates much in excess to those required for weed control and it has also been found to be safe in Zambia (Anton Smith, 1968). A study carried out at Andra Pradesh Agricultural college, in collaboration with Ford Foundation observed that simazine @ 1.1 kg per ha dissolved in 100 gal of water applied one day after sowing gave good weed control without much injury to crop (Chandra singh and Narayan Roa, 1971).

Chamberlain *et al.* (1972) obtained 100 per cent control of pigweed and 50 per cent control of barnyard grass when propazine or atrazine (80% W.P) @ 2.2 kg per ha applied in an emulsion made with 421 water and 4.71 per ha oil as aerial and ground application to sorghum. Kurdikeri (1972) has reported that effective control of weeds are obtained with atrazine spray at 1.5 kg per ha as pre-emergence without any marked injurious effect on sorghum. Highest grain yield (53.5 q/ha) was obtained when atrazine was given as pre-emergence spray @ 1.5 kg a.i. per ha supplemented with 3 hoeings as compared to other treatments.

Mahendra Singh *et al.* (1973) indicated that the use of weedicides significantly reduced the number of weeds. However, propazine @ 0.25 kg a.i./ha did not reduce the number of weeds appreciably. Atrazine @ 0.25 and 0.50 kg a.i/ha caused the maximum reduction on weed population. Combination of Atrazine and propazine at low levels showed no measurable influence on weed density. While at higher levels it proved very effective in this regard. This is, presumably due to atrazine or propazine did not show major influence on weed density.

Kachapur *et al.* (1973) revealed that pre-emergence application (0.5 and 1.0 kg/ha) of atrazine resulted in comparatively higher grain yield (14.5 and 13.6 q/ha) than hand weeded crop (11.3 q/ha) in summer. In *Kharif* sorghum, the yield from the atrazine treated plots (20.6 and 21.8 q/ha, respectively in 0.5 and 1.0 kg/ha) was similar to that from hand weeded plots (21.0 q/ha). In both the seasons all other treatments resulted in reduced grain yields as compared to the unweeded control possibly due to herbicidal toxicity. Nevertheless, the grain yield obtained with a combination of atrazine (pre-emergence) followed 2, 4-D (post-emergence) in the kharif trail was comparable to that of found in hand weeding. Weed population and extent of weed growth was greatly reduced by herbicidal application as compared to unweeded control. Atrazine was more effective in checking weed infestation than 2, 4-D.

Upadhyay *et al.* (1981) reported that the pre-emergence application of atrazine @ 1 kg a.i.ha⁻¹ followed by one weeding and hoeing at 6 weeks stage of the crop produced 16.07 q ha⁻¹ grain yield which was significantly superior to the recommended practices of 2 weedings and 2 hoeings at 3 and 6 weeks stage of the crop (10.56 q ha⁻¹) and control (8.98 q

ha⁻¹), in sorghum. Keeping the field free from weeds for forty days, pre-emergence application of atrazine @ 1 kg a.i.ha⁻¹ followed by post-emergence application of 2,4-D @ of 1 kg a.i.ha⁻¹ at 6 weeks stage and pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ followed by one weeding and hoeing at 6 weeks stage proved their efficacy at par, yielding 15.52, 14.08 and 13.74 q ha⁻¹ of sorghum grain respectively. The same treatment had also given maximum additional net income of Rs.686 per ha over the control.

Pre-emergence application of atrazine @ 1.5 kg ha⁻¹ recorded significantly higher grain and stover yield (72.5 and 175.25 q ha⁻¹ respectively) over unweeded control in rainfed maize (Chakor and Awasthi, 1983). According to Yadav *et al.* (1985), simazine and atrazine @ 0.5 and 1.0 kg ha⁻¹ as pre-emergence effectively controlled predominant *Echinochloa colonum* and *Trianthema portulacastrum* and gave significantly higher yield of maize (4137 and 4077 kg ha⁻¹, respectively) than the unweeded check (1944 kg ha⁻¹) and was on par with clean weeded plots (4313 kg ha⁻¹).

Gail (1985) reported that applying some herbicides at 41 and 25 days prior to planting sorghum resulted in weed control, reduced sorghum injury and increased sorghum yields as compared to application at planting. It was necessary to apply cyanazine @ 2.7 kg a.i.ha⁻¹ 41 days prior to planting to avoid sorghum injury. Metolachlor + 2,4-D @ 2.2 + 0.3 kg ha⁻¹ reduced grain yields to an extent of 97, 98 and 99%, while reduced with alachlor + 2,4-D @ 2.8 + 0.3 kg ha⁻¹ was 93,41 and 63%, respectively, when herbicides were applied at 0, 25 and 41 days prior to planting.

Kamta Prasad and Mani (1986) reported that mean reduction in grain yield of rainfed maize was 80.45 per cent in unweeded check as compared to higher grain yield (6065 kg/ha) obtained through pre-emergence application of atrazine (1.25 kg ha⁻¹) followed by earthing up (20 DAS). He also observed that the pre-emergence application of atrazine was highly economical as compared to manual weeding. Balyan and Bhan (1987) also showed that pre-emergence application of atrazine (0.5 kg ha⁻¹) and manual weedings at 3 and 4 weeks after sowing reduced the dry weight of weeds *viz.* *Trianthema portulacastrum* and *Echinochloa colonum* in maize field.

Singh *et al.* (1988) also reported that application of atrazine (1.0 kg ha⁻¹) as pre-emergence reported that higher weed control efficiency (WCE) of 90.7 per cent and grain (60.93 q ha⁻¹) and stover yield 84.07 q ha⁻¹ of maize and which was on par with integrated weed management methods.

Verma and Katyal (1989) reported that application of atrazine (0.5 kg/ha) and terbutryne (0.4, 0.6 and 0.8 kg/ha) reduced the weed density in comparison to weedy check 60 DAS and at harvest in pearl millet crop and also recorded significantly higher tillers/plant, earheads/plant and 1,000 grain weight over weedy check.

According to Varshney (1990) in a two years study, conducted at Mid hills of Meghalaya, showed that application of atrazine @ 2.0 kg ha⁻¹ to maize proved quite effective in controlling weeds (WCE 67 %) and enhancing grain yield by 143 per cent (3636 kg ha⁻¹) over control (1351 kg ha⁻¹).

Elliot and Moody (1990) observed that atrazine was widely used in maize, but it was ineffective against *Rottbollia cochinchinensis*. Gaur *et al.* (1991) reported that preemergent application atrazine @ 0.5 kg per ha completely controlled the broad leaved weeds, however all grassy weeds were not controlled.

Satao and Nalamwar (1992) found that pre-emergence application of atrazine @ 1 kg ha⁻¹ + two weedings at 40 and 60 DAS resulted in lower biomass of weeds and higher sorghum grain yield. The same treatment also recorded lower weed index as compared to pre-emergence application of atrazine @ 1 kg ha⁻¹ with one weeding or ethyl ester of 2, 4-D ha⁻¹ @ 0.90 kg ha⁻¹.

According to Balyan *et al.* (1994) application of atrazine @ 0.25 or 0.5 kg ha⁻¹ at 7 or 14 DAS proved either equally or more effective than its pre-emergence application against carpet weed (*Trianthema portulacastrum*), barnyard grass (*Echinochloa colonum*) and Kondhra (*Digera arvensis*) in maize. Shersingh and Rajput (1995) reported that pre-emergence application of simazine (1.0 kg) and atrazine (1.0 kg) produced maize grain yield (40.2 q ha⁻¹) equal to that of weed free condition.

Thakur and Sharma (1996) also highlighted that atrazine (1.25 kg ha^{-1}) and two hand weedings (20 and 40 DAS) were at par with each other, and resulted in significantly higher grain yield, test weight, and grain weight per cob followed by atrazine @ 0.75 kg ha^{-1} with one hand weeding at 20 DAS in maize.

Wanjari *et al.* (1996) reported that weed free treatment significantly superior to control and pre-emergence application of atrazine @ $0.75 \text{ kg a.i ha}^{-1}$ alone treatment. However, it was at par with rest of the treatments in sorghum. However, in case of non availability of labours, pre-emergence application of atrazine @ $0.75 \text{ kg a.i ha}^{-1}$ +one hoeing during 6th week was equally effective, since the grain yield of cultivators practice of 2 hoeings+2 weedings and pre-emergence application of atrazine @ $0.75 \text{ kg a.i.ha}^{-1}$ + one hoeing at 6th week were at par. Upadhyay *et al.* (1981)

Saini and Angiras (1998) reported that, the application of atrazine (1.50 kg ha^{-1}) as pre-emergence followed by post-emergence application of atrazine (0.70 kg ha^{-1}) gave satisfactory control of weeds and higher grain yield in maize. Atrazine @ 1.0 kg ha^{-1} in combination with a hand weeding at 45 DAS was the most effective in reducing the total number of weeds and recorded the higher grain yield (42.8 q ha^{-1}), fodder yield, weed control efficiency (92.1%), net returns and cost benefit ratio (2.23) (Patel *et al.*, 2000).

In another trial, Sharma *et al.*(2000b) reported that population and biomass of both monocot as well as dicot weeds were significantly lower in atrazine @ 0.5 kg ha^{-1} + inter cultivation at 30 days after sowing followed by atrazine @ 0.5 kg ha^{-1} which was at par with atrazine @ 0.25 kg ha^{-1} + intercultivation. Atrazine in combination with intercultivation was superior over atrazine alone. All the weed control treatments resulted in significant increase in grain yield of sorghum over weedy check. Atrazine @ 0.5 kg ha^{-1} + inter cultivation recorded significantly higher grain yield (22.86 q ha^{-1}) as compared to rest of the treatments except weed free check.

Sharma *et al.* (2000a) reported that the effect of interculture operations at 15 and 30 days of growth integrated with atrazine @ 1 kg ha^{-1} as pre and post-emergence through either spray or sand-mix application was evaluated on rainfed maize (*Zea mays L.*) at Pujab. Results showed that pre-emergent application of atrazine reduced weed population at 15 days growth significantly (74.8-83.6%) compared to control (75-80 no./m²). Post-emergence application of atrazine @ 1 kg ha^{-1} at 15 days of growth after interculture (hoeing) caused a similar reduction (77.1-82.9%) in weed population at 30 days of growth. Atrazine application through spray or sand-mix was equally effective in controlling weeds and increasing grain yield of maize.

Shinde *et al.* (2001) reported that weed free control had the higher plant height, number of leaves per plant, dry matter per plant at harvest and grain yield and was on par with pre-emergence application of atrazine @ $1.0 \text{ kg a.i.ha}^{-1}$ in maize.

Shekhawat and Gautam (2002) observed higher values for all the parameters of maize in weed free control followed by two hand weedings or atrazine @ $1.0 \text{ kg a.i. ha}^{-1}$ compared to untreated control.

Mundra *et al.* (2003) revealed that atrazine @ 0.5 kg ha^{-1} as a pre-emergence + intercultivation at 35 DAS significantly reduced the total weed density and dry weight over other weed control treatments except intercultivation at 25 and 35 DAS. The same treatment also gave maximum values of crop dry matter accumulation, number of cobs plant⁻¹, grain weight cob⁻¹, test weight and grain yield of maize. The same treatment recorded 80.55 % WCE with 92.8 % increase in maize grain yield compared to weedy check.

Kolage *et al.* (2004) reported that among the herbicides, the pre-emergence spraying of atrazine @ 1.0 kg ha^{-1} reduced the weed intensity substantially and recorded lower weed index and maximum weed control efficiency as compared to other herbicides used in *kharif* maize.

Sharma and Goutham (2003) noticed that among atrazine treatments, at the maturity stage plant height, cob weight and shelling percentage in maize were maximum under atrazine applied @ 1 kg per ha as spray between the rows over the atrazine sprayed as blanket spray. Subhendu *et al.* (2004) reported that pre-emergence application of atrazine @ $1.0 \text{ kg a.i. ha}^{-1}$ + one hand weeding at 30 days after sowing recorded higher number of cobs per plant, weight of cob with husk and without husk followed by two hand weedings at 20 and 40 days after sowing.

Kaushik and Shaktawat (2005) revealed that pre-emergent application of atrazine @ 0.5 kg a.i./ha + 1 hoeing at 35 days after sowing recorded significantly increased sorghum plant height, dry matter, grain weight, grain and stover yields over atrazine alone, indicating the importance of hoeing.

Khajanji *et al.* (2006) reported that significantly higher grain yield of maize was obtained with hand weeding twice at 25 and 50 DAS and also in pre-emergence application of atrazine @ 1.0 kg a.i ha⁻¹. Patel *et al.* (2006) reported that pre-emergence application of pendimethalin @ 0.5 kg ha⁻¹ with atrazine @ 0.5 kg ha⁻¹ gave significantly lower density of monocot and dicot weeds at all the intervals and also recorded higher grain yield of maize as compared to all other treatments.

In another trail, atrazine or dimethenamid alone or in combination were compared under conventional row spacing (single rows spaced 91 cm apart on a bed) and twin rows (two rows spaced 20 cm apart on a single bed). Results indicated that *Amaranthus albus* (tumble pigweed) control was 100% with all treatments except dimethenamid @ 0.56 kg ha⁻¹ which controlled about 96%. *Panicum texanum* (Texas panicum) control was less than 80% with dimethenamid @ 0.56 kg/ha and atrazine @0.56 and 1.12 kg/ha under the conventional row spacing (James *et al.* 2004).

Alok Malviya and Bhagwan Singh (2007) revealed that two hand weedings at 20 and 40 DAS proved most effective (WCE 60.74 and 71.78% respectively) followed by alachlor @ 2.0 kg ha⁻¹ + hand weeding at 30 DAS (WCE 55.86 and 68.31% respectively) and reduced the weed density and weed biomass significantly which in turn increased maize yield (3.3 tones ha⁻¹) as compared to weedy check.

Ishya *et al.* (2007) evaluated different types of herbicides and observed that preilachlor + dimethametryne @ 2.5 kg a.i ha⁻¹, cinosulfuron @ 0.05 kg a.i ha⁻¹ and piperophos + cinosulfuron @ 1.5 kg a.i ha⁻¹ performed best as they effectively controlled weeds and increased grain yield of sorghum.

Rao *et al.* (2007) reported that pre-emergence application of atrazine @ 0.5 kg ha⁻¹ + 1 hoeing or interculture with peg tooth-weeder at 35 days after sowing, were on par recorded least weed population and weed dry weight and significantly increased green and dry fodder yields of sorghum by 66-67 per cent.

Pankaj Chopra and Angiras (2008) observed that application of atrazine @ 1.5 kg ha⁻¹ significantly reduced the population and dry matter of total weeds as compared to unweeded check, and was on par with acetachlor @ 1.25 kg ha⁻¹ and increased in the grain yield of maize by 75.2 and 71.1 % by these two herbicides. In maize, pre-emergence application @ 1.0 kg a.i. per ha + one IC at 30 DAS of atrazine as spray or sand broadcasting or butachlor as spray recorded significantly lower weed population, weed dry weight, higher weed control efficiency and higher maize grain and stover yield. (Kumar, 2008)

Deshmukh *et al.* (2008) reported that in maize at 30 DAS, higher weed control efficiency was recorded by pre-emergence application of atrazine @ 1 kg ha⁻¹ which was on par with pre-emergence application of atrazine @ 0.75 kg/ha pre-emergence followed by 1 hand weeding at 45 DAS. The same treatment recorded significantly superior weed control efficiency over rest of treatments. In maize, pre-emergence application of atrazine @ 0.75 kg ha⁻¹ at 60 and 90 DAS followed by 1 hand weeding at 45 DAS recorded significantly superior WCE over rest of the treatments except application of atrazine @ 1 kg ha⁻¹ and weed free check. Similar findings were reported by Kolge *et al.* (2004).

Patrick *et al.* (2009) studied on effects of KIH-485 and flufenacet to acetochlor and s-metochlor applied PRE in grain sorghum. All treatments were combined with 1.12 kg/ha of atrazine for broadleaf weed control. KIH-485 and flufenacet, each at one time (1×) and two times (2×) the labeled rates, controlled large crabgrass by 55 to 76% in 2005 and 94% or more in 2006 and 2007. In 2005, all herbicides controlled to extent of shatter cane less than 20%, and only KIH-485 at the 2× rate controlled shatter cane more than 70 % in 2006 and 2007. Averaged over herbicides, green foxtail was controlled to extent of 98% in 2005, 77% in 2006, and 79% in 2007. Most of the herbicides controlled foxtail by 86% or more when averaged over experiments, however, s-metolachlor at 1×, flufencet at either rate, or atrazine alone did not. Sorghum was not stunted with KIH-485 or flufenacet in two of seven experiments. However, sorghum growth was reduced 23-54% with the 2× rates of KIH-485,

flufenacet, or acetochlor in four experiments. Compared to the weed free control, sorghum stand establishment was reduced by 18% with the 2× rate of flufenacet at Colby in 2006. At Hays in 2005, stand reductions occurred with acetochlor or KIH-485 at the 2× rates and either rate of flufenacet at the 2× rates, respectively. Where precipitation was greatest during the 2 weeks following herbicide application, weed control was the better with these herbicides, but sorghum injury was also maximum.

In a trial to evaluate the efficacy of nicosulfuron and nicosulfuron+rimsulfuron applied alone or in combination with dicamba, metsulfuron and atrazine provided 90 % or greater control of all broadleaf weeds at ALS-resistant sorghum flowering. Sorghum grain yield was higher following all herbicide treatments compared with weedy check (Shane Hennigh *et al.*, 2010).

Hanwen Wu *et al.* (2010) reported that, a pre-plant application of glyphosate @ 900 g a.i ha⁻¹ plus 2, 4-D amine @ 900 g ae/ha or dicamba @ 500 g a.i. ha⁻¹ @ 1 mo before sorghum planting given ≥ 95 % control. Preplant atrazine @ 2,000 g a.i ha⁻¹ controlled flaxleaf fleabane (*Conyza bonariensis*) 83 to 100% in sorghum. At-planting atrazine @ 2,000 or 1,000 g a.i ha⁻¹ can be applied to control new emergence of flaxleaf fleabane and grasses, depending on the weed pressure and spectrum. Flaxleaf fleabane reduced sorghum yield to 65 to 98% if not controlled.

Seemanthini (2011) revealed that pre-emergence application of oxyfluorfen either @ 0.10 or 0.15 kg ha⁻¹ and atrazine @ 1.25 kg per ha significantly reduced the weed density (2.12, 1.47 and 1.47) and weed dry weight (1.74, 1.47 and 1.80 g) at 30 DAS. Weed control index was significantly higher in these three treatments (84.09, 89.54 and 82.88) compared to rest of the treatments except weed free check and recorded higher grain yield of maize.

2.5.2.2 Post-emergence application of herbicides

Pre-emergence herbicides inhibit seed germination and arrest seedling growth of weeds depending on their mode and mechanism of action. Normally a follow up hand weeding is done after pre-emergence herbicide application to achieve satisfactory weed control at least upto the critical period of crop-weed competition. Alternatively sequential application of post-emergence herbicide after pre-emergence application found to be active on late emerging weeds, especially on broad leaved weeds (Singh and Arya, 1994).

Jones (1955) stated that 2,4-D applied @ 0.5, 1 and 2 lb per feddan (1.038 acres) at four different dates 2, 3, 4 and 5 weeks after sowing of irrigated sorghum showed significant reduction of weeds over no application of herbicides. Application of 2, 4-D during 2nd or 3rd week after sowing gave significantly better weed control than application during 4th or 5th week after sowing.

Joglekar *et al.* (1959) stated that application of fernoxone (2,4-D sodium salt) and dicotox (ethyl ester of 2,4-D) each @ 2.5 and 3.75 kg per ha controlled *Striga euphrasiodes* satisfactorily when sprayed after four weeks of sowing. Dicotox was found to be more effective even at lower doses than fernoxone (2,4-D amine salt 55%). 2,4-D (sodium salt 73%), 2,4-D (ethyl ester salt 10%) and MCPA (24.7%) stand in the order of merit in controlling broad leaved weeds (Vaidya, 1959). 2, 4-D ethyl ester and MCPA were more effective when sprayed at 3 weeks stage as compared to 5 weeks stage.

Mishra (1961) reported that even in arid zones , one early hand weeding followed by 2, 4-D @ 2.25 kg per ha controlled the weeds effectively and maintained the crop yield at the same level as that of repeated hand weeding and interculturing.

In a study carried out at Nagapur under water logged conditions where use of implements and hand weeding was difficult, spraying of 2,4-D or MCPA 3 weeks after sowing gave adequate control of broad leaved weeds (Dakshindas, 1961).

Burnside (1967) had also reported that 10 to 30 cm tall sorghum was most tolerant to 2, 4-D. Earlier sprays retarded the root growth or caused abnormalities of stalk bending, delayed maturity and reduced yield. The safest period for post-emergence application to sorghum is the period when the crop is between 10 and 30 cm tall as reported by Hosmani *et al.* (1969).

At Dharwar, Hosmani *et al.* (1969) reported that spraying of 2, 4-D and MCPA @ 1 kg per ha to sorghum crop (S-413) when it was at knee height effectively controlled both dicot and monocot weeds.

Swink (1969) at 22.2 kg per ha controlled the field bind weed (*Convolvulus arvensis*) satisfactorily at Arkansa in Colorado state and gave highest grain yield of sorghum compared to untreated plots.

Sankaran (1970) observed that post-emergence spray of MSMA (Monosodium Methyl arsenate) @ 1-2L/ha coupled with pre-emergence application of propazine @ 0.5 kg/ha effectively controlled weeds in sorghum. However, such an information for different edaphic and agroclimatic conditions is very scanty. Therefore, the present investigation was undertaken to study the effects of various cultural and chemical methods on the control of weeds and the grain yield of sorghum.

Kurdikeri (1972) reported that application of 2, 4-D @ 0.75 to 1.5 kg per ha gave effective control of *Striga* in sorghum. 2, 4-D @ 1 kg per ha gave satisfactory control of weeds in ratoon crop of sorghum (CSH-1) when applied 10 days after ratooning.

Thakur and Singh (1989) noticed that application of atrazine (1.0 kg ha⁻¹) as pre-emergence along with glyphosate (1.5 kg ha⁻¹) as post-emergence at 42 DAS and two hand weeding registered 98 per cent (57.9 q ha⁻¹) and 107 per cent (60.5 q ha⁻¹) increase in maize grain yield respectively over un weeded control (29.2 q ha⁻¹). They also reported that atrazine and glyphosate were more effective against *Cyperus rotundus*.

Sandhu *et al.* (1991) highlighted that the use of atrazine @ 0.75 kg ha⁻¹ and post-emergence at 30 and 50 days after sowing gave a season long control of grasses and broad leaved annual weeds and produced higher grain yield than hand hoeing. The inhibitory effect on growth of *Parthenium hysterophorus* was more pronounced when atrazine (3.0 kg ha⁻¹) was followed by 15 days after spraying of 2, 4-D ethyl ester (1.0 kg ha⁻¹) and diquat (0.5 kg ha⁻¹) combinations (Dwivedi *et al.*, 1987).

A field trial conducted in Rajasthan revealed that pre-emergence application of atrazine (0.5 kg ha⁻¹) followed by post-emergence application of 2,4-D (0.5 kg ha⁻¹) gave satisfactory control of broad leaved weeds (Gaur *et al.*, 1991).

According to Anil Dixit and Gautam (1993) the favourable effect of atrazine on grain yield was at its high pitch under 0.25 kg ha⁻¹ applied at knee high and tasseling stages, preceded by pre-emergence application of atrazine @ 0.75 kg ha⁻¹. They also reported that atrazine not only control the weeds but also increased the photosynthetic rate of maize plants.

Sreenivas and Satyanarayana (1994) reported that effectively checking the weed growth with the pre-emergence application of atrazine (1.0 kg ha⁻¹) and post-emergence application of 2,4 D (Na Salt) @ 0.5 kg ha⁻¹ (or) Glyphosate (1.0 kg ha⁻¹) on 35 to 40 days after sowing of maize. Post-emergence application of bromoxynil (0.42 kg ha⁻¹) plus nicosulfuron (0.035 kg ha⁻¹) on weeds of 10 cm height gave good control and increased the growth and yield of Maize (Carey and Kells, 1995).

Experiment conducted (on sandy loam soil) in winter maize showed that excellent control of weeds *viz.*, *Chenopodium album* and *Avena ludoviciana* achieved by application of atrazine as pre-emergence (0.75 kg ha⁻¹) along with post-emergence atrazine (0.25 kg ha⁻¹) at knee-high and tasseling stages and increased the yield of maize (70 per cent) over weedy check (Dixit and Gautam, 1996).

2, 4-D is the most widely used post-emergence herbicide in sorghum and is reasonably tolerant at 10 to 30 cm in height, Early applications may damage the root system and later treatments may make the plants liable lodge. Lodging caused by interference with root development can be minimised by sowing the crops in furrows and then earthing the plants up. Atrazine is safer when applied post-emergence than pre-emergence, but in rainfed dry planted sorghum where post-emergence applications may not be practicable, it is best to apply atrazine as an incorporated pre-planting treatment (Wicks, 1966; Shetty and Krantz, 1977).

Saini and Angiras (1998) reported that atrazine @ 1.5 kg ha⁻¹ as pre-emergence followed by post-emergence application of atrazine @ 0.7 kg ha⁻¹ resulted in significantly lower dry matter of weeds and higher maize grain yield compared to other treatments.

Weed biomass at harvest was lower (5.59 g per 0.5 m²) while weed control efficiency (69.5 and 69.4%), grain (46.5 and 38.9 q ha⁻¹) and stover yield (94.9 and 94.8 q ha⁻¹) were higher atrazine with 1.0 kg ha⁻¹ as post-emergence treatment during 1994-95 and 1995-96 respectively (Porwal, 2000) in maize.

Sharma *et al.* (2000a) suggested that atrazine can be used as sand mix post-emergence application followed by hoeing at 15 days of growth for effective control of weeds and increased the grain yield of maize by 1.0 t ha⁻¹ in Khandari area of Punjab.

David *et al.* (2004) reported that in the field study, grain sorghum injury from Metsulfuron was decreased when tank mixed with 2, 4-D or dicamba but not when tank mixed with clopyralid or fluroxypyr. Tank mixes of 2, 4-D or dicamba with Metsulfuron did not reduce ivyleaf morningglory or velvetleaf control. At 4 wk after treatment (WAT), ivyleaf morningglory or velvetleaf control. At 4 wk after treatment (WAT), ivyleaf morningglory controlled 95, 84, 59 and 91 velvetleaf was controlled 88, 82, 78 and 95%. In general, a tank mix of Metsulfuron and 2, 4-D caused visible injury to all hybrids at 1 and 2 WAT, but grain sorghum recovered and most hybrids appeared normal at the end of the flowering season. Differential hybrid responses to Metsulfuron + 2,4-D were observed at 1 and 2 WAT in 2001.

Pratap Singh and Mashiat Ali (2004) reported that application of Metsulfuron-methyl was very effective against the broad-leaf weeds and did not have residual effect on succeeding crop. Metsulfuron methyl at 4 g ha⁻¹ was most effective in controlling broadleaf weeds and better than 2, 4-D and farmers practice in increasing wheat yield.

Weed population and dry matter production of weeds were effectively suppressed with pre and post-emergence application of atrazine or metolachlor @ 3.0 kg ha⁻¹ + 2, 4-D @ 1.0 kg ha⁻¹ respectively and increased the grain yield of maize by 13.4 per cent over the unweeded control (Girma and Chinawong, 2005).

Ramesh and Nadanassababady (2005) reported that pre-emergence application of atrazine @ 0.25 kg ha⁻¹ followed by either one hand weeding at 40 DAS or post-emergence application of 2, 4-D @ 0.5 kg ha⁻¹ as well as early post-emergence application of herbicide mixture of atrazine @ 0.125 kg + metolachlor 0.5 kg ha⁻¹ with one hand weeding at 40 DAS kept the weed density and dry weight below the economic threshold level in rainfed maize.

2,4-D is the most widely used herbicide for weed control in grain sorghum. To evaluate an integrated weed management program in grain sorghum with alternative post-emergence herbicides to 2,4-D at registered and reduced rates. Bromoxynil applied at 480, 360, and 240 g/ha provided excellent broadcast without cultivation provided excellent weed control and sorghum yield comparable with 28.5 g/ha. This treatment represented a 32% cost reduction and 50% reduction in herbicide input compared with prosulfuron8 applied at registered rate without cultivation, and 31% cost reduction compared with 2,4-D at the registered rate (590g ae/ha) plus cultivation considered the commercial standard (Enrique *et al.*, 2005)

At Nigeria, the new formulation doses of atrazine from 1.0 to 3.5 kg ha⁻¹ gave 85 to 98 per cent control of *Commelina benghalensis*, *Passiflora foetida*, sedges and *Talinumtriangulare* at 4 weeks after treatment in both the years (Chikoye *et al.*, 2006).

According to Mallikarjun (2008) number of grains per cob, grain weight per cob, shelling percentage, 100 grain weight, total grain yield, stover yield and harvest index was significantly higher in the application of atrazine @ 1.25 kg ha⁻¹ (PRE) fb 2, 4 - D @ 0.5 kg ha⁻¹ (POST).

Kaczmarek *et al.* (2009) reported that application of Dual Gold 960 EC and Trophy 768 EC were applied directly after crop sowing and the other herbicides at the 3-4 leaf stage of sorghum. Weed control effectiveness was assessed 3-4 weeks after herbicide application. Before harvesting, the fresh weight of five sorghum plants and plant density were determined. The research indicated that years of experiments significantly influenced the herbicides selectivity.

Fresh weight of 5 sorghum plants was significantly higher in comparison with the control plants after Trophy 786 EC (in 2006) and Chwastox Turbo 340 SL (in 2008) application, while sorghum density was influenced by Chwastox Turbo 340 SL (in 2006 and 2007) and Banvel 480 SL (in 2007). Maister 310 WG applied with adjuvant Actirob 842 EC caused the total destruction of sorghum.

Joy *et al.* (2010) reported that mesotrione was applied at 52, 105, 157, and 210 g ai/ha in combination with 280 g ai/ha atrazine to grain sorghum at heights of 5 to 20, and 30 cm, which correspond to early POST (EPOST), mid-POST (MPOST), and late POST (LPOST), respectively. All mesotrione rates caused injury at all application timings. Overall, grain injury from mesotrione was greatest at 1 wk after treatment (WAT); plants partially recovered from injury by 4 WAT. Mesotrione applied EPOST injured grain sorghum more than when applied at MPOST and LPOST timings. The EPOST application injured grain sorghum 19 to 88%, whereas injury from MPOST and LPOST application was 1 to 66% and 0 to 69%, respectively, depending on rate.

Application of atrazine 0.25 a.i. ha⁻¹ as PRE + 2 HW at 30 and 45 DAS recorded significantly reduced the population and dry matter accumulation of weeds as compared to control (weedy check) and also the same treatment recorded highest mean grain yield (3658 kg ha⁻¹) which was at par with atrazine 0.25 + pendimethalin 0.5 kg as pre + 2. 4-D 0.5 kg ha⁻¹ as post-emergent (3529 kg ha⁻¹), atrazine 0.50 kg + 1 HW at 30 DAS (3497 kg ha⁻¹) and pendimethalin 0.5 kg + 1 HW 30 DAS (3393 kg ha⁻¹). Infestation of weeds also reduced the plant height, harvest index and yield attributes of sorghum and also recorded highest net returns (₹ 31601 ha⁻¹) and highest B:C ratio (2.86). (AICRP-progress report, 2011-2012)

Shailendra Singh (2011) reported that application of atrazine 1.00 kg ha⁻¹ fb atrazine 1.50 kg ha⁻¹, and atrazine 1.00 kg ha⁻¹ fb 2, 4-D 2.00 kg ha⁻¹ recorded significantly higher growth and yield attributes of maize.

Shantveerayya and Agasimani (2012) reported that at 30 days and harvest stage, sequential application of atrazine @ 0.75 kg ha⁻¹ followed by 2, 4-D @ 1.0 kg ha⁻¹ recorded significantly lower dry weight of weeds and higher weed control efficiency at all stages of maize crop growth and it was on par with mechanical weeding.

2.6 Economics

At Nagapur, Dakshinadas (1961) worked out the economics of weed control by using 2, 4-D in sorghum. Studies revealed that spraying of 2, 4-D @ 1000 ppm twice increased the cost by ₹ 18, while hand weeding and hoeing increased the cost by ₹ 33. The increase in the yield with 2, 4-D spray was to the extent of 27 per cent over control.

Kurdikeri (1972) obtained a net profit of ₹ 818.50 ha⁻¹ with pre-emergence application of atrazine @ 1.5 kg per ha with hoeing as compared to hoeing alone in sorghum. Application of simazine @ 0.25 kg ha⁻¹ registered a lower weeding cost of ₹ 30 ha⁻¹ with additional income of ₹ 806 ha⁻¹ over weedy check in hybrid maize (Rajan *et al.*, 1974).

Combination treatment of simazine and one hand weeding gave similar higher profit of Rs. 3449 ha⁻¹ which was closely followed by two hand weedings (₹ 3295 ha⁻¹) as reported by (Muthukrishnan and Subramanian, 1980).

Winter maize yielded 21 % higher than cultural method of weed control with 1: 1 mixture of atrazine and metolachlor resulting in saving of 37 mandays ha⁻¹ than cultural method of weed control as reported by Dadi *et al.* (1988).

Singh *et al.* (1988) concluded that atrazine (1.0 kg ha⁻¹) recorded higher net returns of ₹ 9486 ha⁻¹ and net return per rupee invested on weed control was ₹ 25.94.

Angiras and Singh (1989) reported that integrating the chemical method of weed control with maize population of 75,000 ha⁻¹ and 50 per cent more than recommended fertilizer registered significantly higher gross return and net return of ₹ 88,520 ha⁻¹ and ₹ 54,100 ha⁻¹ respectively.

In general of pre-emergence application atrazine @ the rate of 0.25-1.0 kg ha⁻¹ followed by manual weed control (40 DAS) under rainfed condition was the most profitable weed control practice and resulted in net return of ₹ 5977 ha⁻¹ compared to net return of ₹ 5616 in farmer's practice (Bhopal Singh *et al.*, 1991).

Sreenivas and Satyanarayana (1994) reported that higher net returns were recorded with Atrazine @ 1.0 kg ha⁻¹ followed by post-emergence application of 2,4-D (Na-salt) @ 0.5 kg ha⁻¹ followed by atrazine @ 1.0 kg ha⁻¹ followed by glyphosate @ 1.0 kg ha⁻¹.

Hand weeding twice at 20 and 40 DAS gave maximum net returns of ` 6198 ha⁻¹ and net returns per rupee investment of 1.57 over atrazine applied @ 0.5 kg ha⁻¹ which recorded a net return of ` 4651 ha⁻¹ with net return per rupee investment of 1.26 (Padmavathi and Gopaldaswamy, 1995).

Patel *et al.* (2000) reported that higher net returns and cost benefit ratio (2.23) by application of atrazine @ 1.0 kg ha⁻¹ in combination with hand weeding at 45 DAS.

Porwal *et al.* (2000) reported that maximum benefit-cost ratio (3:32) was achieved with post-emergence application of atrazine @ 1.0 kg ha⁻¹ at 30-35 DAS in maize.

Subramanyam *et al.* (2001) concluded that the pre-emergence application of Atrazine @ 1.0 kg ha⁻¹ + metolachlor @ 1.0 kg ha⁻¹ with one hand weeding at 40 DAS found effective and economical weed management practices for irrigated maize.

Pandey *et al.* (2002) reported that all the weed control treatments recorded considerably higher returns over weedy check, which ranged from ` 4010 to 15,576 ha⁻¹. Higher additional returns of ` 15,576 ha⁻¹ was recorded in pre-emergence alachlor @ 1.00 kg ha⁻¹ applied in integration with hand weeding at 30 DAS in baby corn.

Kolage *et al.* (2004) reported that pre-emergence application of atrazine @ 1.0 kg ha⁻¹ recorded maximum net returns of ` 12,766 ha⁻¹ and B: C ratio of 2.50 as compared to other herbicides.

The most economical and effective method of weed control was the pre-emergence application of atrazine + one hoeing + one hand weeding at 20 DAS which recorded the highest cost:benefit ratio of 1:3.68 (Kamble *et al.*, 2005).

Roa *et al.* (2007) reported Pre-emergence application of atrazine alone or atrazine + interculture with peg tooth-weeder at 35 days after sowing gave high net returns and benefit : cost ratio.

In maize, pre-emergence application @ 1.0 kg a.i. per ha + one IC at 30 DAS of atrazine as spray or sand broadcasting or butachlor as spray recorded significantly higher net returns and benefit cost ratio. (Kumar, 2008)

Shailendra Singh (2011) reported that significantly higher net returns and B: C ratio were recorded in application of atrazine 1.00 kg ha⁻¹ fb atrazine 1.50 kg ha⁻¹, and atrazine 1.00 kg ha⁻¹ fb 2, 4-D 2.00 kg ha⁻¹ in maize.

2.7 Nutrient uptake

Weeds remove moisture and nutrients at a faster rate than sorghum in the early stages due to its slower growth, thus affecting crop growth and yield if they are not controlled (Sankaran and Mani, 1972).

Kaushik and Shaktawat (2005) revealed that pre-emergent application of atrazine @ 0.5 kg a.i./ha + 1 hoeing at 35 days after sowing recorded significantly increased nitrogen and phosphorous uptake by grain and stover over atrazine alone.

Roa *et al.* (2007) reported weed control treatments caused significantly higher uptake of N and P and crude protein content. Atrazine @ 0.5 kg/ha recorded significantly higher uptake of N by 81.5% and of P by 78.8% by sorghum over unweeded control. In addition to Atrazine, cultural practices either by hoeing or peg tooth-weeder further increased the uptake of N and P significantly by the sorghum crop. This was mainly owing to higher dry-fodder yield.

Satao *et al.* (1993) reported that pre-emergence application of atrazine @ 1 kg ha⁻¹ + two hand weedings recorded the higher uptake of N, P and K, grain and fodder yield of sorghum.

Sreenivas and Satyanarayana (1994) reported that the nutrient uptake by the crop can be increased by effectively checking the weed growth with the pre-emergence application of atrazine (1.0 kg ha^{-1}) and post-emergence application of 2,4 D (Na Salt) @ 0.5 kg ha^{-1} (or) Glyphosate (1.0 kg ha^{-1}) on 35 to 40 days after sowing of maize.

Pankaj Chopra and Angiras (2008) observed that application of atrazine @ 1.5 kg ha^{-1} significantly reduced the population and dry matter of total weeds as compared to unweeded check, and also significantly increased the N, P and K uptake by the crop (93.3, 105.3 and 95.4 % by the former and 87.0, 88.8 and 88.9 % respectively by the latter) and lower depletion of N, P and K by weeds (79.4, 87.2 and 81.5% by the former and 81.9, 88.7 and 83.5% respectively by the latter herbicide).

3. MATERIAL AND METHODS

A field experiment was undertaken during *kharif* 2011 to study the Effect Integrated weed management in *kharif* sorghum (*Sorghum bicolor* (L.) Moench) at Sorghum Research Scheme, Main Agricultural Research Station, Dharwad under rainfed condition. The details of the materials used and the methods adopted during the course of investigation are presented in this chapter.

3.1 Experimental site (Location)

The experiment was conducted at Main Agricultural Research Station, Dharwad. Dharwad is located at 15° 26' N latitude, 75° 07' E longitude and at an altitude of 678 m above mean sea level. Dharwad comes under Northern Transition Zone (Zone-8) of Karnataka which lies between the Western Hilly Zone (Zone-9) and Northern Dry Zone (Zone-3).

3.2 Soil characteristics of experimental site

The soil of experimental site was clay loams comprising maximum clay content (70.1%) with bulk density and particle density of 1.15 Mg m⁻³ and 2.65 g/cc, respectively. Composite soil samples were collected from each replication at a depth of 0 to 15 cm before sowing and were analyzed for various physical and chemical characteristics. The data of soil analysis along with methods followed are furnished in Table 1. The soil pH was 6.5, it was low in available nitrogen and available phosphorus and high in available potassium.

3.3 Climatic conditions

The data on weather parameters such as rainfall (mm), mean maximum and minimum temperature (°C) and relative humidity (%) recorded at Meteorological Observatory, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during the experimental year and the mean of the last 60 years (1950-2010) are presented in Table 2.

The annual rainfall received during 2011 was 922.7 mm distributed in 72 rainy days (Table 2). The rainfall during cropping period (June-Sept) was 532 mm which was well distributed during crop growth period. The rainfall received in the month of June (194 mm) and July (131 mm) ensured adequate stored moisture for germination, emergence and early establishment of seedlings. Further the adequate quantity and uniform distribution of rainfall during August, September ensured proper growth and development of sorghum. A slightly higher rainfall was received in the month of June (86.49 mm) (compared to normal) encouraged the vigorous growth of weeds. The rainfall during cropping season was much higher than normal and was well distributed. Thus resulted in good growth and development of crop.

The rainfall received during the dry sown and normal sown condition was 541.0 mm and 447.0 mm respectively. The maximum normal rainfall was received in the month of October (219.7 mm) followed by July (194 mm). The rainfall received in all the months during the crop growth period except August and September was less than the average of past 61 years. The mean maximum temperature during the period of experimentation was ranged from 26.2°C (August) to 29.9°C (October), while the minimum temperature was ranged from 19.5°C (October) to 21.3°C (June). The mean relative humidity varied from 73 per cent in the month of October to 87 per cent in the month of August 2011.

3.4 Previous cropping history

Hybrid sorghum during *kharif* followed by chickpea during *rabi* season were cultivated during the year 2010-11.

Table 1: Physical and chemical properties of the experimental site

Particulars	Value	Methods employed
1. Physical properties		
Particle size distribution		International pipette method (Piper, 2002)
Coarse sand (%)	11.2	
Fine sand (%)	23.9	
Silt. (%)	18.7	
Clay (%)	70.1	
Texture class	Clay loam	
Bulk density(Mg m ⁻³)	1.15	Piper (2002)
Particle density (g/cc)	2.65	
2. Chemical properties		
Available N (kg /ha)	192	Alkaline permanganate method [Subbaiah and Asija (1956)]
Available P ₂ O ₅ (kg /ha)	15.9	Olsen's method (Jackson,1973)
Available K ₂ O (kg /ha)	390	Flame photometer method (Jackson,1973)
Zinc (ppm)	0.8	
Iron (ppm)	4.5	
Organic carbon (%)	0.54	Walkley and Black's wet oxidation method (Jackson,1973)
pH (1:2.5, soil: water)	6.5	pH meter (Piper,2002)
Electrical conductivity (dS/m)	0.08	Jackson (1973)

Table 2: Monthly meteorological data for the experimental year 2011 and average of 60 years (1950-2010) at Main Agricultural Research Station, UAS, Dharwad

Months	Rainfall (mm)		Rainy day	Mean Temperature (°C)				Relative humidity (%)	
	2011	1950-2010		Maximum		Minimum		2011	1950-2010
				2011	1950-2010	2011	1950-2010		
January	0	0.039	0	29.2	28.7	12.5	14.07	59	64.81
February	21.6	0.684	1	30.8	31.6	14	16.56	48	54.41
March	0.8	15.02	0	32.2	34.9	18.6	19.71	44	64.24
April	77.4	41.54	3	34.9	36.6	20.2	20.11	57	78.05
May	66.6	65.74	6	34.7	35.2	21.3	20.95	61	75.78
June	194	107.51	14	27.5	30.2	21.3	21.68	84	86.29
July	131	137.72	14	26.9	27.3	20.6	20.85	85	89.18
August	124.2	150.45	13	26.2	27.2	20.7	20.16	87	88.6
September	82.8	132.33	11	28.1	27.9	19.9	19.96	80	86.68
October	219.7	97.63	9	29.9	29.5	19.5	18.65	73	79.4
November	4.6	53.49	1	29.8	28.9	15.8	15.93	55	73.62
December	0	2.26	0	29.6	27.8	13.7	13.2	57	69.12
Total	922.7	804.38	72	-	-	-	-	-	-

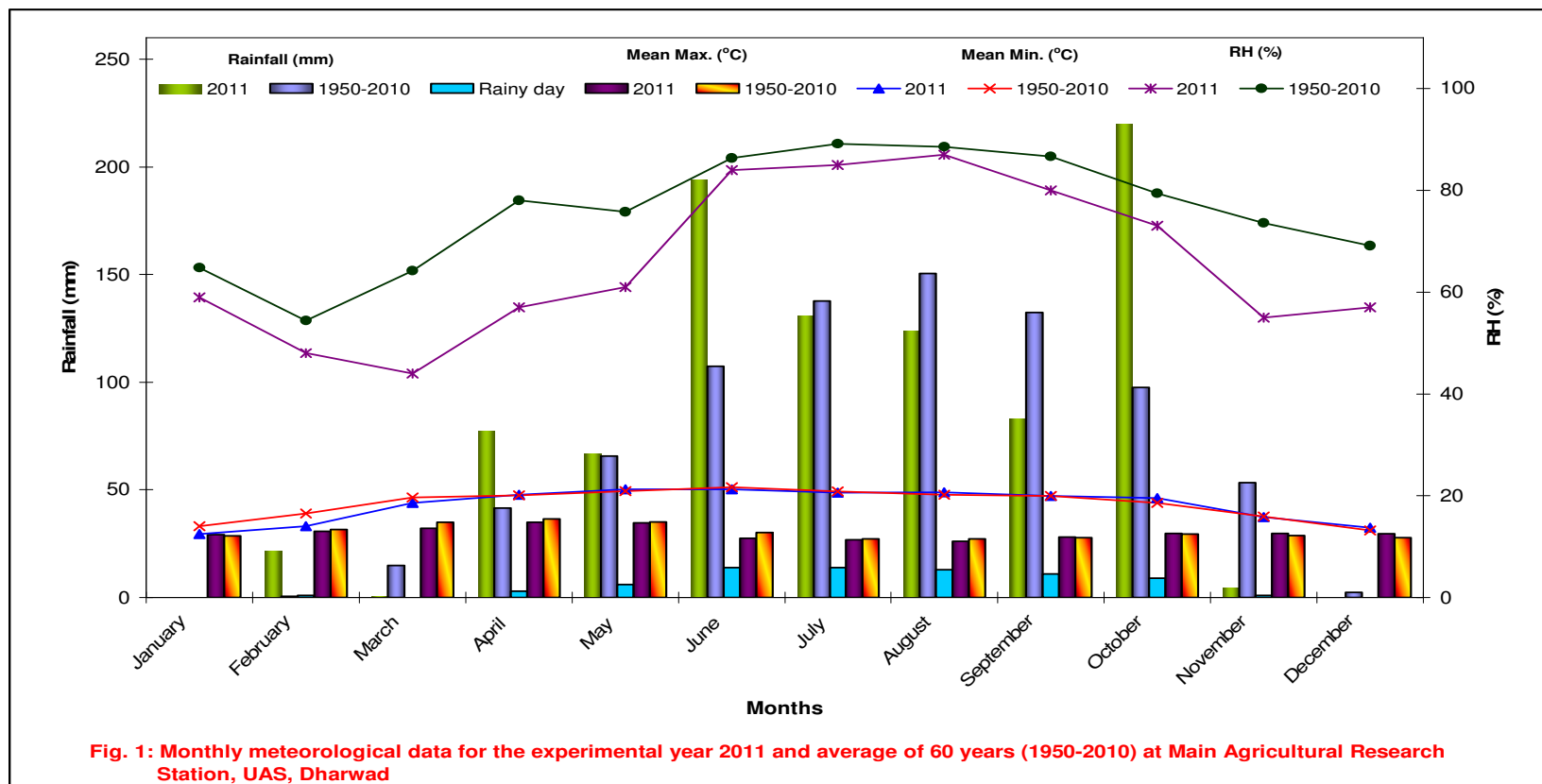


Fig. 1: Monthly meteorological data for the experimental year 2011 and average of 60 years (1950-2010) at Main Agricultural Research Station, UAS, Dharwad

3.5 Experimental details

The details of the experiment with regard to treatments, design adopted and plot size are given below.

3.5.1 Treatment details

The experiment consisted of 10 treatments and the details are as follows

T₁: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha⁻¹(POST) at 25 DAS.

T₂: Atrazine @ 0.5 kg a.i. ha⁻¹(PRE) fb Atrazine @ 0.75 kg a.i. ha⁻¹(POST) at 25 DAS.

T₃: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.5 kg a.i. ha⁻¹(POST) at 25 DAS.

T₄: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.75 kg a.i. ha⁻¹(POST) at 25 DAS.

T₅: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha⁻¹(POST) at 25 DAS.

T₆: Atrazine @ 0.5 kg a.i. ha⁻¹(PRE) fb Metsulfuron methyl @ 6 g a.i. ha⁻¹(POST) at 25 DAS

T₇: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) + 1HW+2 IC (RPP)

T₈: Farmers practice (1 HW fb 2 IC)

T₉: Weed free check

T₁₀: Weedy check

(PRE = Pre emergent, POST = Post emergent, HW = Hand weeding, DAS = Days after sowing, fb = followed by, a.i = active ingredient, ha = hectare, RPP = Recommended package of practice and IC = Inter cultivation)

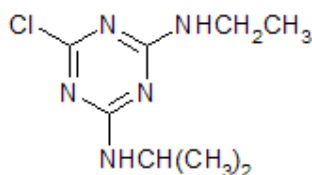
3.5.2 Design and layout

The experiment was laid out in randomized complete block design (RCBD) having ten treatment combinations and replicated thrice with gross plot size of 5.4 m × 4.5 m and net plot size of 3.6 m×3.9 m (Fig.2). A general view of the experiment plots is depicted in plate 1.

3.5.3 Description of the herbicides used

a. Atrazine

- i. Chemical Name: 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5- triazine-2, 4-Diamine
- ii. Trade name: Atrataf, Attack, Atrasaan, Dhanuzine, Solaro and Surya
- iii. Empirical Formula: C₈H₁₄ClN₅
- iv. Molecular Weight: 218.1
- v. Structural Formula:



vi. Solubility: In water 33 mg/l (pH 7, 22°C). In ethyl acetate 24, acetone 31, dichloromethane 28, ethanol 15, toluene 4.0, n-hexane 0.11, n-octanol 8.7 (all in g/l, 25°C).

vii. Formulations: 80% W.P.

viii. Application:

Atrazine is a selective systemic herbicide, absorbed principally through the roots, but also through the foliage, with translocation acropetally in the xylem and accumulation in the apical meristems and leaves. Earlier atrazine was the number one herbicide in the world because of its highest acreage of use in maize, sorghum, millets across countries of the world. It is more soluble in water (33 ppm water solubility), which provides an edge over the latter for use in the dry land areas. It has been reported in maize and millets, resulting in greener foliage and more proteinaceous grains. The shoot/ foliage activity of atrazine upon post-emergence application could be enhanced by mixing a phytobland oil in the spray which can even control established annual weeds.

Atrazine is a broad-spectrum but mainly a broad-leaved killer herbicide with some action on grasses. However, *Acrachne racemosa*, a rainy season annual grass is not controlled by it. *Commelina benghalensis* control is also poor. It is effective against *Trianthema monogynal portulacastrum*, *Digera arvensis*, *Echinochloa colona/ crus-galli*, *Eleusine indica*, *Xanthium strumarium*, *Brachiaria sp.*, *Cleome viscosa*, *Polygonum sp.*, *Dactyloctenium aegyptium*, *Eragrostis sp.*, *Digitaria sanguinalis/ adscendens*, *Borreria hispida*, *Ageratum conyzoides*, *Amaranthus sp.*, *Chenopodium album* and *Spergula arvensis*. Atrazine could be applied in maize (1.0 kg a.i. ha⁻¹), sugarcane (2.0 kg a.i. ha⁻¹), potato (0.25 kg a.i. ha⁻¹) and pearl millet (0.5 kg a.i. ha⁻¹).

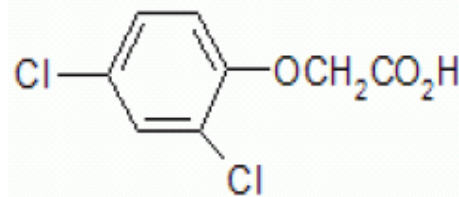
b. 2, 4-D Sodium salt

Chemical name: 2, 4- dichlorophenoxy acetic acid

Common name: 2, 4-D sodium salt-80% (WSA,BSI)

Trade name: Fernoxone

Chemical and structural formula: C₈H₆Cl₂O₃ (221.0)



Uses: Post-emergence control of annual and perennial broad-leaved weeds in cereals, maize, sorghum, grassland, established turf, grass seed crops, orchards (Pome fruit and stone fruit), cranberries, asparagus, sugar cane, rice, forestry, and on non-crop land (including areas adjacent to water) at 0.28-2.3kg/ha.

Mode of action: 2, 4-D sodium salt once it has contacted the plant, it is readily absorbed and translocated within the phloem through the tissues and causes disruption of its phloem tissues and consequent dislocation of photosynthesis symptoms and kills even perennial weeds efficiently. It accumulates in the meristematic regions. Principally and normal cell division ceases, affects respiration rate. Increases turgor pressure of cells, causes abnormal growth and close of stomata resulting in death of plants.

LEGEND

T₁: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha⁻¹(POST) at 25 DAS
fb IC at 35 DAS.

T₂: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha⁻¹(POST) at 25 DAS
fb IC at 35 DAS.

T₃: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.5 kg a.i. ha⁻¹(POST) at 25 DAS fb
IC at 35 DAS.

T₄: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.75 kg a.i. ha⁻¹(POST) at 25 DAS
fb IC at 35 DAS.

T₅: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha⁻¹(POST) at
25 DAS fb IC at 35 DAS.

T₆: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha⁻¹(POST) at
25 DAS fb IC at 35 DAS.

T₇: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) + 1HW+2 IC (Check-RPP)

T₈: Farmers practice (1 HW fb 2 IC)

T₉: Weed free check

T₁₀: Weedy check

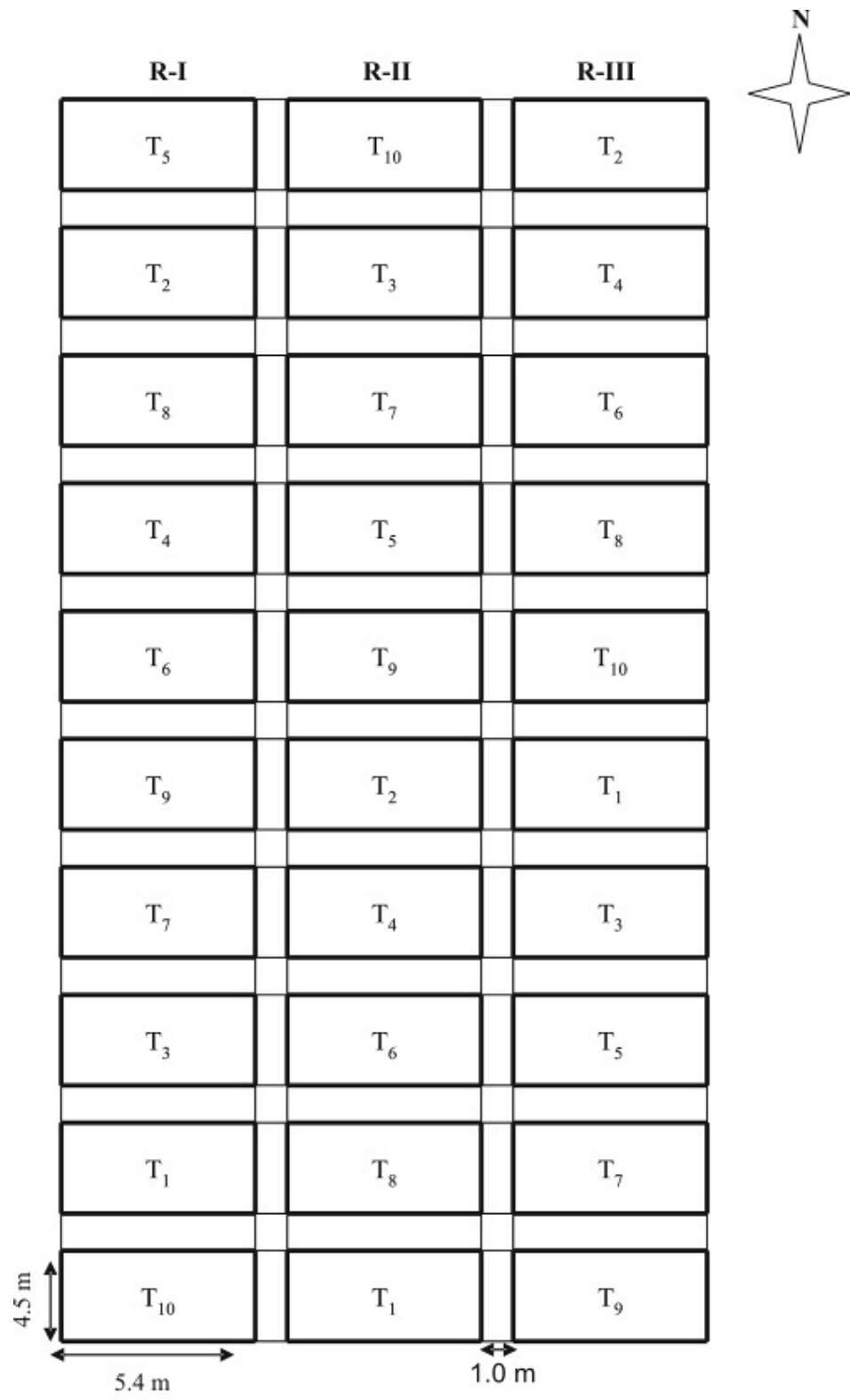


Fig. 2: Plan of layout of the experiment

Fig. 2: Plan of layout of the experiment



Plate 1: General view of experiment

c. Metsulfuron methyl

Chemical Name:

2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid

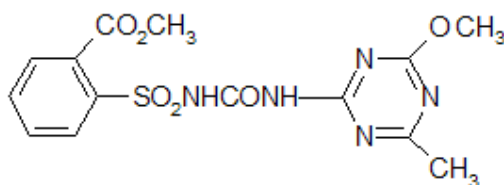
Trade name: DuPont™ Escort® XP, Aim, Brushoff, Metmac, Ally, Associate, Parti-San

Met, Bushwacker, Metsun, Esteem, Brushkiller, Metsulfuron, Lynx Sum-Met

Empirical formula : C₁₄H₁₅N₅O₆S

Molecular Weight : 381.4

Structural Formula :



Solubility: In water 0.55 (pH 5), 2.79 (pH 7), 213 (pH 9) (all in g/l, 25 °C).

In xylene 0.58, ethanol 2.3, methanol 7.3, acetone 36, dichloromethane 121 (all in g/l, 20 °C).

Formulations: 60% WDG; 20%WDG; 60%WP;10%WP;20%WP

Mode of Action: Metsulfuron methyl inhibits acetolactate synthase (ALS), a key enzyme needed in the biosynthesis of the branched amino acids isoleucine, leucine and valine in plants. Animals do not possess this enzyme to synthesize proteins.

3.6 Cultural operations

3.6.1 Land Preparation

The land was ploughed once, clods were crushed by using spring cultivator twice followed by two harrowing. Stubbles and weeds were cleaned from the experimental area and it was brought to fine tilth and leveled to prepare fine seed bed.

3.6.2 Seeds and sowing

The sorghum (CSH-14) seeds were sown @ 7.5 kg ha⁻¹ on 14th June 2011 at 45 cm rows 15 cm spacing, and seeds were covered by harrowing.

3.6.3 Fertilizer application

Nitrogen, phosphorus and potassium were applied at the rate of 100:75:25 kg N, P₂O₅ and K₂O per hectare in the form of urea, di- ammonium phosphate and muriate of potash. Nitrogen application was made in two splits; 50 % at the time of sowing along with full doze of P and K, and remaining 50 % N was top dressed at 30 DAS.

3.6.4 Gap filling

Gap filling was done at eight days after sowing to maintain optimum plant population. Thinning was carried out fifteen days after sowing retaining one healthy seedling per hill.

3.7 Imposition of treatments

3.7.1 Application of herbicides

The required amount of herbicides for the experimentation was calculated by using the following formula.

$$F = \frac{R \times 100}{\text{Purity (\%)}} \times \frac{A}{10,000}$$

Where:

F = Formulated product required in kg or lit/ha.

R = kg a.i. ha⁻¹ to be sprayed (recommended rate)

A = Area to be sprayed (m²)

Thus, calculated amount of herbicide was sprayed to each treatment using knapsack sprayer with a spray volume of 500 liters of water per hectare.

3.7.2 Pre-emergence application of herbicides

Pre-emergence herbicides were sprayed uniformly after sowing of the crop. The pre-emergence application was made on the soil surface uniformly by using 750 liters of spray solution with minimum trampling.

3.7.3 Post-emergence application of herbicide

Post-emergence herbicides were applied uniformly at 25 DAS as per the treatments in 750 liters of spray solution.

3.7.4 Hand weeding and intercultivation

Hand weeding was carried in T₇, T₈ and T₉ and also on bunds sides and paths whenever the weeds emerged in order to keep the experimental site clean. One intercultural operation was done at 30 DAS done in all treatments except T₁₀.

3.7.5 Aftercare

Care was taken to remove all the weeds in weed free check plot when ever weeds appeared followed by intercultivation at 30 days after sowing with hand hoe. Furadon granules (at the rate of 5 kg ha⁻¹) were applied into the leaf whorls of each plant at 22 days after sowing to reduce the incidence of shoot fly.

3.7.6 Harvesting

The border row plants along with earheads were cut manually from all the sides of each plot and then net plots were harvested on 20th October, 2011. First ear heads were harvested from the plants in the net plot and were sun dried. Then fodder was harvested at ground level and sun dried in the field. The ear heads were sun-dried, threshed and grain yield per plot was recorded. Similarly stover yield per plot was also recorded after sun drying in the field and stover yields per ha were computed.

3.8 Collection of experimental data

3.8.1 Observations on weed

3.8.1.1 Weed flora

The important weed flora presented in the experimental plot during the period of experimentation was recorded. In the experimental site, the weed infestation was predominantly consisted of grassy weeds, broad-leaved weeds and sedges. Among broad-leaved weeds, *Commelina benghalensis*, *Knoxia mollis*, *Mollugo disticha*, *Digera arvensis*, *Phyllanthus maderpatensis*, *Euphorbia geniculata*, *Corchorus trilocularis*, *Cynotis cristata*; among the grassy weeds, *Cynodon dactylon*, *Brachiaria eruciformis* and among sedges, *Cyperus rotundus* were reported.

3.8.1.2 Weed control and crop phytotoxicity ratings

Visual ratings were taken at 7, 14 and 21 DAS (pre-emergence as well as post-emergence) to know the extent of weed control and the extent of toxicity caused by different herbicides as given by Rao (1986). Both the ratings were expressed in the scale ranging between 0 – 10 (Table 3).

3.8.1.3 Weed count species wise

The number of weeds present in 1 m² area in each plot was counted at 30, 60, 90 DAS and at harvest. These weeds were further classified into sedges, grasses and broad-leaved weeds and their population was recorded.

3.8.1.4 Dry weight of weeds (g/m²)

Dry weight of weeds was recorded at 30, 60, 90 DAS and at harvest. The weeds were uprooted from the destructive sampling area of 1 m² and were oven dried to a constant weight at 70 °C and the dry weight of weeds was expressed in g per m².

3.8.1.5 Weed control efficiency (%)

Weed control efficiency (WCE) denotes the magnitude of weed reduction due to the weed control treatment. The weed control efficiency was calculated by using the formula given by Mani *et.al* (1976)

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in weedy check (g)} - \text{Dry weight of weeds in treatment plot (g)}}{\text{Dry weight of weeds in weedy check (g)}} \times 100$$

3.8.1.6 Weed index (%)

Weed index is the reduction in crop yield due to the presence of weeds in comparison with weed free plot expressed as percentage. In other words weed index expresses the competition offered by weeds measured by per cent reduction in yield owing to their presence in the field (Gill and Vijayakumar, 1969).

Table 3: Qualitative description of treatment effects on weeds and crop in the visual scoring scale of 0 to 10

Effect	Rating	Weed	Crop
None	0	No control	No injury , normal
Slight	1	Very poor control	Slight stunting, injury or discolouration
	2	Poor control	Some stand loss, stunting or discolouration
	3	Poor to deficient control	Injury more pronounced but not persistent
Moderate	4	Deficient control	Moderate injury, recovery possible
	5	Deficient to moderate control	Injury more persistent, recovery doubtful
	6	Moderate control	Near severe injury, no recovery possible
Severe	7	Satisfactory control	Severe injury, and stand loss
	8	Good control	Almost destroyed a few plants surviving
	9	Good to excellent control	Very few plants alive
Complete	10	Complete control	Complete destruction

(Rao, 1986)

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

Where,

X = Total yield from the weed free plot

Y = Total yield from the treatment for which weed index has to be calculated

3.8.2 Observations on crop

3.8.2.1 Growth parameters

Five plants from net plot area were randomly selected and observations on following growth parameters were recorded at 30, 60, 90 DAS and at harvest.

3.8.2.1.1 Plant height (cm)

The plant height was measured from the base of fully opened top leaf to the ground level and expressed in centimeters.

3.8.2.1.2 Leaf area per plant

Maximum length and breadth of 3rd leaf from the top of each of the five plants were recorded. The product of length x breadth was multiplied by total number of green leaves per plant and the multiplication factor of 0.747 was used to calculate the total leaf area per plant (Sticker *et al.*, 1961).

3.8.2.1.3 Leaf area index (LAI)

Leaf area index (LAI) was calculated as per the procedure given by Sestak *et al.* (1971).

$$\text{LAI} = \frac{\text{Leaf area per plant (dm}^2\text{)}}{\text{Land area occupied by the plant (dm}^2\text{)}}$$

3.8.2.1.4 Dry matter production and partitioning

The five randomly selected plants were used to record the dry matter production at 30, 60, 90 DAS and at harvest. The tagged plants were uprooted and separated into leaves, stem and ear. They were oven dried separately at 70°C for 48 hours and the dry weight was recorded in gram plant⁻¹.

3.8.2.2 Yield components and yield

The ear from the five plants selected for taking growth observations at the time of harvest were used for recording following observations on yield components.

3.8.2.2.1 Grain weight per ear

The grains from the sun dried ear of five plants were separated and the weight of the grains was recorded. The average grain weight per ear was expressed as gram per ear.

3.8.2.2.2 Test weight (g)

The weight of hundred grains (g) was recorded from the grains randomly drawn from the grain yield obtained from each of the net plot.

3.8.2.2.3 Grain yield (q ha⁻¹)

The ears from net plot were threshed, cleaned and grain weight was recorded in kg per net plot and expressed in quintals per hectare.

3.8.2.2.4 Stover yield (t ha⁻¹)

Stover yield was recorded after complete sun drying of stalks from each net plot and expressed in tonnes ha⁻¹.

3.8.2.2.5 Harvest index

Harvest index was defined as the ratio of economic yield to biological yield and expressed in percentage. Harvest index was estimated as per the formula suggested by (Donald, 1962)

$$HI (\%) = \frac{\text{Economic yield (kg /ha)}}{\text{Biological yield (kg /ha)}} \times 100$$

3.9 Uptake of N, P, K in weeds and crop

The plant and weed samples collected at 60 DAS and harvest were oven dried and ground in a Wiley mill to pass through two mm sieve. The sieved samples were used for the estimation of nitrogen, phosphorus and potassium content in plants.

3.9.1 Nitrogen

Nitrogen content in plants and weed samples was estimated by modified Microjeldahl's method as outlined by Jackson (1967) and was expressed in percentage Nitrogen content (Appendix I and II) and dry weight were used to calculate the total uptake of nitrogen and expressed in kg/ha.

3.9.2 Phosphorus

Phosphorus was estimated by Vanedomolybdate method in diacid mixture as detailed by Jackson (1967). The intensity of the colour developed was measured in a spectrophotometer using blue filter. The amount of phosphorus was calculated by referring to the standard curve and expressed in percentage Phosphorus content and dry weight were used to calculate the total uptake of phosphorus and expressed in kg/ha.

3.9.3 Potassium

Potassium content was estimated from diacid digest material using Flame Photometer as described by Muhr *et.al.* (1965) and was expressed in percentage Potassium content and dry weight were used to calculate the total uptake of potassium and expressed in kg/ha.

$$\text{Nutrient uptake (kg/ha)} = \frac{\% \text{ of nutrient concentration} \times \text{biomass (kg/ha)}}{100}$$

3.10 Economics

The market prices of both grain and stover were obtained from Agriculture Produce Marketing Committee Dharwad. Economics was worked out by using cost of cultivation, gross income and net income. The prices of the inputs that were prevailed at the time of the use were considered to work out the cost of cultivations (Appendix I). The net income (₹ ha⁻¹) was calculated by deducting cost of cultivation from the gross income.

The B: C ratio was calculated as under:

$$\text{Benefit: cost ratio} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Total cost of cultivation (₹ . ha}^{-1}\text{)}}$$

3.11 Transformation

Data on weed count have showed high degree of variation. A linear relationship between the means and variance was observed and therefore, the data on weed count was subjected to $(x+0.5)^{1/2}$ transformation to make analysis of variance valid as suggested by Bartlett (1947).

3.12 Statistical analysis and interpretation of data

The data collected at different growth stages of crop were subjected to statistical analysis as described by Panse and Sukhatme (1967). Statistical analysis was carried out based on mean values obtained. The level of significance used in 'F' and 'T' test was $P= 0.05$. Critical difference values were calculated wherever 'F' test was significant.

3.13 Correlation studies

Correlation coefficients were worked out for grain yield versus growth parameters (all stages), yield parameters (harvest), nutrient uptake (60DAS and harvest), weed count (all stages), weed dry weight (all stages), weed control index ((all stages) and nutrient uptake by weeds as per the procedure given by Gomez and Gomez (1983).

4. EXPERIMENTAL RESULTS

Present investigation was conducted under *Kharif* season to find out the efficiency of pre-emergence herbicides *viz.*, atrazine and post-emergence herbicides *viz.*, atrazine, 2,4-D and metsulfuron methyl for controlling weeds in *kharif* sorghum grown at Sorghum Research Scheme, Main Agricultural Research Station, Dharwad under rainfed condition. The results obtained in this study on integrated weed management and their effect on sorghum growth, yield and yield components are presented in this chapter.

4.1 Observations on weeds

4.1.1 Weed flora observed in experimental site

The important grassy weeds, broad leaved weeds and sedges observed in association with sorghum under rainfed situation in the experimental site are presented in Table 4. Most of the weeds of *kharif* season were observed in the experimental area. Among the different categories, broad leaved weeds dominated the weed flora.

4.1.2 Weed population

Weed population (grassy weeds, broad leaved weeds, sedges and total) recorded at 30, 60, 90 DAS and at harvest indicated significant influence of different weed management practices at all the stages of crop growth (Tables 5, 6 and 7).

4.1.2.1 Grassy weeds (m^{-2})

The data on grassy weeds recorded per m^2 area at 30, 60, 90 DAS and at harvest are presented in Table 5. At all the growth stages, weed free check recorded significantly lower number of grassy weeds per m^2 and weedy check recorded significantly higher number of grassy weeds per m^2 as compared to other treatments.

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha^{-1} fb post-emergence application of 2, 4-D @ 0.5 kg a.i. ha^{-1} (T_3) recorded significantly lower number of grassy weeds per m^2 (2.12) as compared to other treatments except atrazine @ 0.5 kg a.i. ha^{-1} fb atrazine @ 0.75 kg a.i. ha^{-1} (T_2) (2.43) and atrazine @ 0.5 kg a.i. ha^{-1} fb 2, 4-D @ 0.75 kg a.i. ha^{-1} (T_4) (2.40) which were on par.

A 60 DAS, number of grassy weeds per m^2 were significantly lower in pre-emergence application of atrazine @ 0.5 kg a.i. ha^{-1} followed by (fb) post-emergence application of atrazine @ 0.75 kg a.i. ha^{-1} (T_2) (2.31) as compared to atrazine @ 0.5 kg a.i. ha^{-1} fb 2, 4-D @ 0.75 kg a.i. ha^{-1} (T_4) (2.73) and was on par with rest of the treatments.

At 90 DAS, all the weed management practices *viz.*, atrazine @ 0.5 kg a.i. ha^{-1} fb post-emergence application of atrazine @ 0.5 kg a.i. ha^{-1} (T_1), atrazine @ 0.5 kg a.i. ha^{-1} fb atrazine @ 0.75 kg a.i. ha^{-1} (T_2), atrazine @ 0.5 kg a.i. ha^{-1} fb 2,4-D @ 0.5 kg a.i. ha^{-1} (T_3), atrazine @ 0.5 kg a.i. ha^{-1} fb 2,4-D @ 0.75 kg a.i. ha^{-1} (T_4), atrazine @ 0.5 kg a.i. ha^{-1} fb metsulfuron methyl @ 4 g a.i. ha^{-1} (T_5), atrazine @ 0.5 kg a.i. ha^{-1} fb metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6), atrazine @ 0.5 kg a.i. ha^{-1} + 1HW+2 IC (T_7), Farmers practice were on par with each other.

At harvest, pre-emergence application of atrazine @ 0.5 kg a.i. ha^{-1} fb post-emergence application metsulfuron methyl @ 4 g a.i. ha^{-1} recorded significantly lower number of grassy weeds per m^2 (2.54) as compared to atrazine @ 0.5 kg a.i. ha^{-1} fb Atrazine @ 0.5 kg a.i. ha^{-1} (T_1) (3.13), Atrazine @ 0.5 kg a.i. ha^{-1} (PRE) fb 2,4-D @ 0.5 kg a.i. ha^{-1} (T_3) (3.08), atrazine @ 0.5 kg a.i. ha^{-1} fb 2,4-D @ 0.75 kg a.i. ha^{-1} (T_4) (3.34) and was on par with rest of treatments.

4.1.2.2 Sedges (m^{-2})

Number of sedges per m^2 recorded at 30, 60, 90 DAS and at harvest is presented in Table 6. At all the growth stages, weedy check recorded significantly higher number of sedges per m^2 as compared to other treatments.

Table 4: Dominant weeds noticed in the experimental area

Weed species	Common name	Family
A. Grassy weeds		
<i>Chloris barbata</i> Swartz.	Fingergrass	Poaceae
<i>Cynodon dactylon</i> (L.) Pers.	Bermuda grass	Poaceae
<i>Dinebra retroflexa</i> (Vahl.) Panzer	Viper grass	Poaceae
<i>Echinochloa crus-galli</i> (L.) Beauv.	Barnyardgrass, watergrass	Poaceae
<i>Echinochloa colona</i> (L.) Link.	Water grass	Poaceae
<i>Panicum repens</i> L.	Torpedograss, panicgrass, gingergrass	Poaceae
B. Sedge		
<i>Cyperus rotundus</i> L.	Purple nutsedge	Cyperaceae
C. Broad leaved weeds		
<i>Acalypha indica</i> L.	Copperleaf	Euphobiaceae
<i>Ageratum conyzoides</i> L.	Billgoatweed	Asteraceae
<i>Amaranthus viridis</i> L.	Pig weed	Amaranthaceae
<i>Alternanthera sessilis</i> L.	Sessile joyweed	Amaranthaceae
<i>Blumea mollis</i> (D. Don.) Merr.	Spreading hogweed	Asteraceae
<i>Commelina benghalensis</i> L.	Day flower	Commelinaceae
<i>Cyanotis cusullata</i> Kunth.	Teddy bear plant	Commelinaceae
<i>Corchorus</i> spp.		Tiliaceae
<i>Euphorbia geniculata</i> (L.) Orteg.	Spurge	Euphobiaceae
<i>Merremia emarginata</i> Hallier F.	-	Convolvaceae
<i>Mollugo verticillata</i> L.	Carpet weed/ green carpet weed	Molluginaceae
<i>Phyllanthus fraternus</i> L.	Seed-Under-Leaf	Euphorbiaceae
<i>Parthenium hysterophorus</i> L.	Carrot grass	Asteraceae
<i>Physalis minima</i> L.	Ground cherry	Solonaceae
<i>Sonchus arvensis</i> D. C.	Perennial sowthistle	Asteraceae

Table 5: Number of grassy weeds per m² in *Kharif* sorghum as influenced by weed management practices

Treatments		Number of grassy weeds per m ²			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	*2.60 (6.33)	2.34 (5.00)	2.73 (7.00)	3.13 (9.33)
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	2.43 (5.41)	2.31 (4.83)	2.54 (6.00)	2.91 (8.00)
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	2.12 (4.03)	2.41 (5.33)	2.68 (6.67)	3.08 (9.00)
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	2.40 (5.33)	2.73 (7.00)	2.91 (8.00)	3.34 (10.67)
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	3.01 (8.59)	2.41 (5.33)	2.61 (6.33)	2.54 (6.00)
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	2.67 (6.67)	2.48 (5.67)	2.48 (5.67)	2.67 (6.67)
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	2.79 (7.34)	2.41 (5.33)	2.79 (7.33)	2.79 (7.33)
T ₈	Farmers practice (1 HW fb 2 IC)	3.58 (12.35)	2.48 (5.67)	2.73 (7.00)	2.67 (6.67)
T ₉	Weed free check	0.71 (0.00)	1.22 (1.00)	1.34 (1.33)	1.34 (1.33)
T ₁₀	Weedy check	3.72 (13.33)	4.06 (16.00)	4.78 (22.33)	5.24 (27.00)
Mean		2.60	2.49	2.76	2.97
S.Em.±		0.12	0.13	0.18	0.14
CD (P = 0.05)		0.34	0.40	0.54	0.41

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

* Figures indicating ($\sqrt{x+0.5}$) transformed values, Figures in parentheses are indicating original values

Table 6: Number of sedges per m² in *Kharif* sorghum as influenced by weed management practices

Treatments		Number of sedges per m ²			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	*0.88 (0.33)	1.22 (1.00)	1.34 (1.33)	0.88 (0.33)
T ₂	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	0.88 (0.33)	1.05 (0.67)	0.71 (0.00)	0.71 (0.00)
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	1.05 (0.67)	0.88 (0.33)	0.88 (0.33)	0.71 (0.00)
T ₄	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	0.88 (0.33)	0.88 (0.33)	0.71 (0.00)	0.71 (0.00)
T ₅	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	1.56 (2.00)	1.58 (2.00)	1.22 (1.00)	1.22 (1.00)
T ₆	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	1.34 (1.33)	1.46 (1.67)	1.22 (1.00)	1.05 (1.00)
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	0.88 (0.33)	1.05 (0.67)	0.71 (0.00)	0.88 (0.33)
T ₈	Farmers practice (1 HW fb 2 IC)	1.34 (1.33)	1.17 (1.00)	0.88 (0.33)	1.22 (1.00)
T ₉	Weed free check	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
T ₁₀	Weedy check	2.11 (4.00)	2.73 (7.00)	2.54 (6.00)	1.86 (3.00)
Mean		1.16	1.27	1.09	1.01
S.Em.±		0.13	0.15	0.09	0.09
CD (P = 0.05)		0.38	0.44	0.27	0.28

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice
 * Figures indicating ($\sqrt{x+0.5}$) transformed values, Figures in parentheses are indicating original values

A 30 DAS, number of sedges per m² were significantly lower in weed free check (T₉) (0.71) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (1.56), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (1.34), Farmers practice (T₈) (1.34) and was on par with rest of treatments.

At 60 DAS, weed free check (T₉) and atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (0.88) recorded significantly lower number of sedges per m² (0.71) as compared atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (1.58), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (1.46), atrazine @ 0.5 kg a.i. ha⁻¹ followed by (fb) atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (1.22), farmers practice (T₈) (1.17) and was on par with rest of treatment.

At 90 DAS, pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application atrazine @ 0.75 kg a.i. ha⁻¹ (T₂), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄), atrazine @ 0.5 kg a.i.+1 HW+2 IC (T₇) (0.71), weed free check (T₉) (0.71) recorded significantly lower number of sedges per m² (0.71) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (1.22), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (1.22) and atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (1.34) and was on par with rest of treatments.

At harvest, pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (0.71), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃), atrazine @ 0.5 kg a.i. ha⁻¹ fb of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄), weed free check (T₉) (0.71) recorded significantly lower number of sedges per m² (0.71) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (1.22), atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (1.05) and farmers practice (T₈) (1.22) and was on par with rest of treatments.

4.1.2.3 Broad leaved weeds (m⁻²)

Number of broad leaved weeds per m² recorded at 30, 60, 90 DAS and at harvest is presented in Table 7. At 30 and 90 DAS, weed free check recorded significantly lower number of broad leaved weeds per m² and at all growth stages, weedy check recorded significantly higher number of broad leaved weeds per m² as compared to other treatments.

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) recorded significantly lower number of broad leaved weeds per m² (2.19) as compared to farmers practice (T₈) (3.56) and was on par with rest of the weed management practices.

At 60 DAS, weed free check (T₉) recorded significantly lower number of broad leaved weeds per m² (1.22) as compared to other treatments, but it was on par with atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (1.56), atrazine @ 0.5 kg a.i. ha⁻¹ followed by (fb) 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (1.56) and atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (1.46).

At 90 DAS, pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly lower number of broad leaved weeds per m² (1.34) as compared to other treatments except pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb Post-emergence application of 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (1.46) with which it was on par.

At harvest, broad leaved weeds per m² were significantly lower in weed free check (T₉) (1.05) as compared to other treatments except pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (1.46) with which it was on par.

4.1.2.4 Total number of weeds (m⁻²)

Total number of weeds recorded per m² area at 30, 60, 90 DAS and at harvest is presented in Table 8. At all the growth stages, weed free check recorded significantly lower total number of weeds per m² and weedy check recorded significantly higher total number of weeds per m² as compared to other treatments.

Table 7: Number of broad leaved weeds per m² in *Kharif* sorghum as influenced by weed management practices

Treatments		Number of broad leaved weeds per m ²			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	*2.54 (6.00)	1.68 (2.33)	2.47 (5.67)	2.68 (6.67)
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	2.34 (5.00)	1.56 (2.00)	2.12 (4.00)	2.34 (5.00)
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	2.54 (6.00)	1.56 (2.00)	1.46 (1.67)	1.86 (3.00)
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	2.26 (4.67)	1.46 (1.67)	1.34 (1.33)	1.46 (1.67)
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	2.34 (5.00)	2.00 (3.67)	2.34 (5.00)	2.54 (6.00)
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	2.19 (4.33)	1.95 (3.33)	2.54 (6.00)	2.41 (5.33)
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	2.48 (5.67)	1.68 (2.33)	2.41 (5.33)	2.48 (5.67)
T ₈	Farmers practice (1 HW fb 2 IC)	3.56 (12.17)	3.67 (13.00)	3.72 (13.33)	3.13 (9.33)
T ₉	Weed free check	0.71 (0.00)	1.22 (1.00)	0.71 (0.00)	1.05 (0.67)
T ₁₀	Weedy check	4.85 (23.00)	5.55 (33.00)	5.87 (34.00)	5.79 (33.00)
Mean		2.68	2.23	2.50	2.57
S.Em.±		0.12	0.14	0.14	0.15
CD (P = 0.05)		0.37	0.42	0.43	0.45

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice
 Figures in parentheses are indicating original values

* Figures indicating ($\sqrt{x+0.5}$) transformed values

Table 8: Total number of weeds per m² in *Kharif* sorghum as influenced by weed management practices

Treatments		Total number of weeds per m ²			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	*6.03 (12.67)	5.24 (8.33)	6.55 (14.00)	6.69 (16.33)
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	5.65 (10.74)	4.92 (7.50)	5.37 (10.00)	5.96 (13.00)
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	5.72 (10.70)	4.85 (7.67)	5.02 (8.67)	5.64 (12.00)
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	5.54 (10.33)	5.08 (9.00)	4.96 (9.33)	5.51 (12.33)
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	6.91 (15.59)	5.99 (11.00)	6.17 (12.33)	6.31 (13.00)
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	6.20 (12.33)	5.90 (10.67)	6.25 (12.67)	6.30 (13.00)
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	6.15 (13.34)	5.14 (8.33)	5.91 (12.67)	6.15 (13.33)
T ₈	Farmers practice (1 HW fb 2 IC)	8.48 (25.85)	7.32 (19.67)	7.33 (20.67)	7.03 (17.00)
T ₉	Weed free check	2.12 (0.00)	3.16 (2.00)	2.76 (1.33)	3.10 (2.00)
T ₁₀	Weedy check	10.67 (40.33)	12.34 (53.33)	13.19 (62.33)	12.89 (63.00)
Mean		6.45	5.99	6.35	6.56
S.Em.±		0.27	0.35	0.31	0.37
CD (P = 0.05)		0.79	1.03	0.92	1.11

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice
 * Figures indicating ($\sqrt{x+0.5}$) transformed values, Figures in parentheses are indicating original values

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly lower total number of weeds per m² (5.54) as compared atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (6.91), farmers practice (8.48) which were on par and was on par with rest of treatments.

At 60 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) recorded significantly lower total number weeds per m² (4.85) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (5.99), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (5.90), farmers practice(T₈) (7.32) and was on par with rest of the treatments.

At 90 DAS, the total number of weeds per m² were significantly lower in pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (4.96) as compared to rest of treatment except atrazine @ 0.5 kg a.i. ha⁻¹ followed by (fb) atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (5.37) and atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (5.03) with which it was on par.

At harvest, pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (5.51) recorded significantly lower total number of weeds per m² as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (6.69), farmers practice (T₈) (7.03) and it was on par with rest of treatments.

4.1.3 Weed control rating and crop phytotoxicity rating

4.1.3.1 Weed control ratings

Visual observations on weed control ratings were recorded at 7, 14 and 21 days after spraying of pre-emergence and post-emergence herbicides (Table 9).

After pre-emergence herbicides spray

At 7 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (9.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (9.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (9.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (9.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (9.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (9.0), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇) (9.0), Farmers practice (T₈) (6.0) recorded good to excellent control of weeds as compared to weedy check (T₁₀) (0.0). Weed free check (T₉) recorded complete control of weeds (10.0).

At 14 DAS, similar trend as that of 7 DAS was observed.

At 21 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇) (8.0), Farmers practice (T₈) (6.0) recorded good to excellent control of weeds as compared to weedy check (T₁₀) (0.0). While weed free check (T₉) recorded complete control of weeds (10.0).

After Post-emergence herbicide spray

At 7 days after spray, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ followed by (fb) post-emergence application of 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₁) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (7.67), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (7.67), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇) (8.0), Farmers practice (T₈) (8.0) recorded good control of weeds. Pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (6.33), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (7.00) recorded satisfactory control of weeds as compared to weedy check (T₁₀) (0.0). While, weed free check recorded complete control of weeds (T₉) (10.0).

At 14 Days after spray, atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ (T₁), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇), Farmers practice (T₈) recorded good to excellent control of weeds.

At 21 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (7.33), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (8.0), atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (7.67), atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (7.33), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇) (8.0), Farmers practice (T₈) (8.0) recorded good control of weeds as compared to weedy check (T₁₀) (0.0). While weed free check (T₉) recorded complete control of weeds (10.0).

4.1.3.2 Crop phytotoxicity ratings

The visual observations on crop phytotoxicity ratings were recorded in pre-emergence and post-emergence herbicides spray at 7, 14 and 21 days after sowing (Table 10).

After pre-emergence herbicides

There was no phototoxic injury (0.00) on crop at 7, 14 and 21 days after spray with pre-emergence application of atrazine.

After post-emergence herbicide spray

At 7 days after spray of herbicide, slight stunting, injury or discolouration of leaves and stem was observed in pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ followed by (fb) post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (1.00). While there was some crop stand loss, stunting or discolouration of leaves and stem in pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (2.0). There was no phototoxic injury on crop in rest of the treatments.

At 14 days after spray, some crop stand loss, stunting or discolouration of leaves and stem was observed in pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (2.0). While in atrazine @ 0.5 kg a.i. ha⁻¹ fb Post-emergence application of metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (3.0) sprayed plots, Injury more on crop was pronounced but not persistent. The rest of the treatments, recorded there was no phototoxic injury on crop.

At 21 days after spray of herbicide atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (2.0) sprayed plots some crop stand loss, stunting or discolouration of leaves and stem. Moderate injury crop recovery was observed in atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (4.0) sprayed plots. There was no phototoxic injury on crop rest of the treatments.

4.1.4 Dry weight of weeds (g m⁻²)

Dry weight of weeds recorded at different growth stages differed significantly due to various weed management practices (Table 11). At all the growth stages, weed free check recorded significantly lower dry weight of weeds per m² and weedy check recorded significantly higher dry weight of weeds per m² as compared to other treatments.

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ followed by (fb) post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly lower dry weight of weeds m² (2.15) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (2.60) farmers practice (T₈) (3.75) and was on par with rest of the weed management practices.

Table 9: Weed control ratings (0-10 scale) as influenced by weed management practices in *Kharif* sorghum

Treatments		After pre emergence herbicides			After post emergence herbicides		
		7 DAS	14 DAS	21 DAS	7 DAS	14 DAS	21 DAS
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	9.00	9.00	8.00	6.33	8.67	7.33
T ₂	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	9.00	9.00	8.00	7.00	9.00	8.00
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	9.00	9.00	8.00	8.00	9.00	8.00
T ₄	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	9.00	9.00	8.00	8.00	9.00	8.00
T ₅	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	9.00	9.00	8.00	7.67	8.33	7.67
T ₆	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	9.00	9.00	8.00	7.67	8.33	7.33
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	9.00	9.00	8.00	8.00	9.00	8.00
T ₈	Farmers practice (1 HW fb 2 IC)	6.00	6.00	6.00	8.00	9.00	8.00
T ₉	Weed free check	10.00	10.00	10.00	10.00	10.00	10.00
T ₁₀	Weedy check	0.00	0.00	0.00	0.00	0.00	0.00

DAS= Days after spraying, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 10: Phytotoxicity ratings (0-10 scale) as influenced by weed management practices in *Kharif* sorghum

Treatments		After pre emergence herbicides			After post emergence herbicides		
		7 DAS	14 DAS	21 DAS	7 DAS	14 DAS	21 DAS
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	0.00	0.00	0.00	0.00	0.00	0.00
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	0.00	0.00	0.00	0.00	0.00	0.00
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	0.00	0.00	0.00	0.00	0.00	0.00
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	0.00	0.00	0.00	0.00	0.00	0.00
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	0.00	0.00	0.00	1.00	2.00	2.00
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	0.00	0.00	0.00	2.00	3.00	4.00
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	0.00	0.00	0.00	0.00	0.00	0.00
T ₈	Farmers practice (1 HW fb 2 IC)	0.00	0.00	0.00	0.00	0.00	0.00
T ₉	Weed free check	0.00	0.00	0.00	0.00	0.00	0.00
T ₁₀	Weedy check	0.00	0.00	0.00	0.00	0.00	0.00

DAS= Days after spraying, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP Recommended package of practice

At 60 DAS, weed management practices like, atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ (T₁), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇), Farmers practice (T₈) were on par with each other in recording dry weight of weeds.

Same trend as that of 60 DAS was noticed both at 90 DAS and at harvest.

4.1.5 Weed control efficiency (WCE) (%)

Weed control efficiency computed at 30, 60, 90 DAS and at harvest differed significantly due to various weed management practices (Table 12). At all the growth stages, weed free check recorded significantly higher weed control efficiency as compared to other treatments.

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher weed control efficiency (47.20 %) as compared atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (35.70), farmers practice (T₈) (8.88) and was on par with rest of the weed management practices.

At 60 DAS, weed management practices viz., T₁, T₂, T₃, T₄, T₅, T₆, T₇ and T₈ were on par with each other in recording weed control efficiency.

Same trend which was observed at 60 DAS was noticed at 90 DAS.

At harvest, weed control efficiency was significantly higher in pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (52.10 %) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (39.67 %), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (40.71 %) and it was on par with rest of the weed management practices.

4.1.6 Nutrient uptake of weeds (60 DAS and harvest)

Nutrient uptake by the weeds was computed at 60 DAS and at harvest differed significantly due to sequential application of pre and post-emergence herbicides (Table 13). At all the growth stages, weedy check recorded significantly higher nutrient uptake by the weeds as compared to other treatments.

Nitrogen

At 60 DAS, weed free check recorded significantly lower nitrogen uptake (2.83 kg/ha) as compared to other weed management practices except atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) and atrazine @ 0.5 kg a.i. ha⁻¹ + 1 HW+2 IC (T₇) with which it was on par. Among herbicidal treatments (T₁ to T₇), nitrogen uptake was significantly lower in atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (4.26 kg/ha) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (7.97 kg/ha) and was on par with rest of treatments.

At harvest, nitrogen uptake was significantly lower in weed free check (5.0 kg/ha) as compared to other weed management practices except atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) with which it was on par. Among herbicidal treatments (T₁ to T₇), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly lower nitrogen uptake (6.40 kg/ha) as compared to other treatments except atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (9.23 kg/ha) with which it was on par.

Phosphorous

At 60 DAS, Weed free check recorded significantly lower phosphorous uptake (2.23 kg/ha) as compared to other weed management practices, atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (3.00 kg/ha), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (2.65 kg/ha), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (3.26 kg/ha) with which it was on par.

Table 11: Dry weight of weeds (g per m²) in *Kharif* sorghum as influenced by weed management practices

Treatments		Dry weight of weeds (g per m ²)			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	*2.35 (5.07)	2.02 (3.60)	3.33 (10.60)	3.09 (9.08)
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	2.19 (4.30)	1.96 (3.33)	3.08 (9.00)	2.97 (8.33)
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	2.18 (4.28)	1.87 (3.00)	2.94 (8.14)	2.92 (8.00)
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	2.15 (4.13)	1.88 (3.07)	2.91 (7.95)	2.90 (8.17)
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	2.60 (6.24)	2.21 (4.40)	3.26 (10.18)	3.64 (12.74)
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	2.32 (4.93)	2.18 (4.27)	3.13 (9.31)	3.61 (12.68)
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	2.41 (5.34)	1.96 (3.33)	3.25 (10.07)	3.02 (8.64)
T ₈	Farmers practice (1 HW fb 2 IC)	3.75 (13.61)	2.27 (4.70)	3.35 (11.38)	3.16 (9.49)
T ₉	Weed free check	0.71 (0.00)	1.14 (0.80)	1.68 (2.36)	1.21 (0.77)
T ₁₀	Weedy check	4.08 (16.13)	4.67 (21.33)	6.20 (37.98)	6.23 (39.37)
Mean		2.47	2.22	3.32	3.28
S.Em.±		0.12	0.11	0.15	0.27
CD (P = 0.05)		0.37	0.45	0.45	0.79

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice
 Figures in parentheses are indicating original values

* Figures indicating ($\sqrt{x+0.5}$) transformed values

Table 12: Weed control efficiency (%) in *Kharif* sorghum as influenced by weed management practices

Treatments		Weed control efficiency (%)			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	*41.63 (68.59)	57.42 (83.14)	47.37 (72.05)	48.89 (74.01)
T ₂	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	45.88 (73.39)	58.64 (84.35)	51.31 (76.21)	50.86 (76.09)
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	46.02 (73.51)	60.16 (85.61)	53.97 (78.47)	51.97 (77.38)
T ₄	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	47.20 (74.47)	60.66 (85.94)	54.45 (78.99)	52.10 (76.66)
T ₅	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	35.70 (61.32)	53.49 (79.39)	48.19 (73.01)	39.67 (62.95)
T ₆	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	41.97 (69.24)	53.95 (80.01)	50.66 (75.52)	40.71 (64.68)
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	40.42 (66.99)	58.64 (84.35)	48.45 (73.43)	49.89 (74.92)
T ₈	Farmers practice (1 HW fb 2 IC)	8.88 (15.65)	52.23 (78.02)	45.21 (69.92)	47.91 (73.15)
T ₉	Weed free check	82.47 (100.00)	76.44 (96.25)	75.12 (93.81)	80.31 (97.45)
T ₁₀	Weedy check	-	-	-	-
	Mean	39.02	53.16	47.47	46.23
	S.Em.±	2.62	2.99	3.28	3.37
	CD (P = 0.05)	7.80	8.88	9.73	10.01

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice
 Figures in parentheses are indicating original values

* Figures indicating ($\sqrt{x+0.5}$) transformed values

Among weed management practices (T_1 to T_7), atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4), recorded significantly lower phosphorous uptake (2.65 kg/ha) as compared to atrazine @ 0.5 kg a.i.ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T_1) (3.49 kg/ha), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T_2) (4.42 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (4.44 kg/ha) and atrazine @ 0.5 kg a.i.ha⁻¹ + 1 HW+2 IC (T_7) (5.17 kg/ha) and it was on par with rest of treatments.

At harvest, phosphorous uptake was significantly lower in weed free check (2.07 kg/ha) as compared to other weed management practices except atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (2.97 kg/ha) with which it was on par. Among herbicidal treatments (T_1 to T_7), atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4), recorded significantly lower phosphorous uptake (2.97 kg/ha) as compared to others except atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T_3) (4.55 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (4.91 kg/ha) with which it was on par.

Potassium

At 60 DAS, weed free check recorded significantly lower potassium uptake (4.32 kg/ha) as compared to other weed management practices except atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (7.62 kg/ha) with which it was on par. Among herbicidal treatments (T_1 to T_7), atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded significantly lower potassium uptake (7.62 kg/ha) as compared to atrazine @ 0.5 kg a.i.ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T_2) (11.65 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (11.70 kg/ha) and was on par with rest of treatments.

At harvest, potassium uptake was significantly lower in weed free check (4.05 kg/ha) as compared to other weed management practices except atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T_3) (7.22 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (5.39 kg/ha) with which it was on par. Among herbicidal treatments (T_1 to T_7), potassium uptake was significantly lower in atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (POST) (T_4), as compared to other treatments except atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T_3) (7.22 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹ (PRE)+1 HW+2 IC (9.36 kg/ha) with which it was on par.

4.2 Growth components of sorghum

4.2.1 Plant height

The observations on plant height of sorghum recorded at 30, 60, 90 DAS and at harvest are presented in Table 14. Weedy check recorded significantly lower plant height at 60 DAS (69.3 cm), 90 DAS (107.6 cm) and at harvest (118.8 cm) as compared to other treatments.

At 30 DAS, there was no significant effect of different weed management practices on plant height.

At 60 DAS, weed free check recorded significantly higher plant height (129.8 cm) as compared to Atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (110.7 cm), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (90.2 cm) and was on par with rest of the treatments. Among the herbicidal treatments, pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded higher plant height (128.4 cm) as compared to others.

Similar trend as that of 60 DAS was observed at 90 DAS and at harvest.

4.2.2 Leaf area

Leaf area at 30, 60 and at 90 DAS differed significantly due to different weed control treatments (Table 15).

At 30 DAS, weed free check recorded significantly higher leaf area (13.18 dm² plant⁻¹) as compared to farmers practice (11.09 dm² plant⁻¹), weedy check (9.50 dm² plant⁻¹) and it was on par with rest of the treatments. Among herbicidal treatments (T_1 to T_7), all treatments were on par with each other in recording leaf area.

Table 13: Nutrient uptake (kg/ha) by weeds in *Kharif* sorghum crop as influenced by weed management practices

Treatments		60 DAS			At harvest		
		N	P	K	N	P	K
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	7.97	5.49	11.53	12.26	5.40	11.19
T ₂	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	7.03	4.42	11.65	10.94	5.99	10.19
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	7.51	3.00	10.93	10.49	4.55	7.22
T ₄	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	4.26	2.65	7.62	6.40	2.97	5.39
T ₅	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	5.27	3.26	10.19	9.23	4.91	11.21
T ₆	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	5.73	4.44	11.70	10.63	5.99	11.55
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	5.28	5.17	11.25	11.28	5.54	9.36
T ₈	Farmers practice (1 HW fb 2 IC)	7.83	4.86	9.88	10.51	5.88	10.33
T ₉	Weed free check	2.23	2.23	4.32	5.00	2.07	4.05
T ₁₀	Weedy check	20.52	14.73	20.23	24.48	14.93	22.26
	Mean	7.76	5.02	10.93	10.73	5.82	10.28
	S.Em.±	1.10	0.57	1.32	1.21	0.75	1.38
	CD (P = 0.05)	3.26	1.71	3.93	3.60	2.21	4.11

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 14: Plant height (cm) of *Kharif* sorghum as influenced by weed management practices

Treatment		Plant height (cm)			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	18.3	121.1	156.7	154.0
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	18.6	123.0	154.0	156.0
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	18.8	125.2	159.2	155.4
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	18.9	128.4	159.7	156.3
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	17.9	110.7	140.9	141.4
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	18.0	90.2	137.0	138.2
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	18.5	124.0	156.3	154.2
T ₈	Farmers practice (1 HW fb 2 IC)	18.0	123.5	152.3	150.2
T ₉	Weed free check	19.3	129.8	162.1	159.7
T ₁₀	Weedy check	17.5	69.3	107.6	111.8
Mean		18.4	114.5	147.9	147.7
S.Em.±		0.4	3.3	3.2	3.3
CD (P = 0.05)		NS	9.9	9.6	9.8

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

At 60 DAS, weed free check recorded significantly higher leaf area ($32.51 \text{ dm}^2 \text{ plant}^{-1}$) as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} ($25.11 \text{ dm}^2 \text{ plant}^{-1}$), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} ($18.31 \text{ dm}^2 \text{ plant}^{-1}$), weedy check ($14.00 \text{ dm}^2 \text{ plant}^{-1}$) and was on par with rest of the weed management practices. Among the herbicidal treatments (T_1 to T_7), pre-emergence application of atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb post-emergence application of 2, 4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ ($31.84 \text{ dm}^2 \text{ plant}^{-1}$) as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} (T_5) ($25.11 \text{ dm}^2 \text{ plant}^{-1}$), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6) ($18.31 \text{ dm}^2 \text{ plant}^{-1}$) and was on par with rest of the treatments and was on par with rest of the treatments.

At 90 DAS, leaf area was significantly higher in weed free check ($28.21 \text{ dm}^2 \text{ plant}^{-1}$) as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} (T_5) ($23.88 \text{ dm}^2 \text{ plant}^{-1}$), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6) ($17.96 \text{ dm}^2 \text{ plant}^{-1}$), weedy check (T_{10}) ($10.93 \text{ dm}^2 \text{ plant}^{-1}$) and was on par with rest of the weed management practices. Among the herbicidal treatments (T_1 to T_7), pre-emergence application of atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb post-emergence application of 2, 4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ ($26.77 \text{ dm}^2 \text{ plant}^{-1}$) recorded significantly higher leaf area as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6) ($17.96 \text{ dm}^2 \text{ plant}^{-1}$) and was on par with rest of the treatments.

4.2.3 Leaf area index

Leaf area index at 30, 60 and at 90 DAS differed significantly due to different weed control treatments (Table 16).

At 30 DAS, pre-emergence application of atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb post-emergence application of 2, 4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_4) recorded significantly higher leaf area index (1.95) compared to farmers practice (T_8) (1.64), weedy check (T_{10}) (1.41) and was on par with rest of the treatments.

At 60 DAS, weed free check recorded significantly higher leaf area index as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} (T_5) (3.68) atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb Metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6) (2.71), weedy check (T_{10}) (2.07) and was on par with rest of the weed management practices. Among the herbicidal treatments (T_1 to T_7), leaf area index was significantly higher in atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2, 4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_4) (4.72) as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} (T_5) (3.68), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6) (2.71) which was on par with rest of the treatments.

Similar trend as that of was observed at 60 DAS at 90 DAS.

4.2.4 Dry matter accumulation in leaves (g plant^{-1})

The various integrated weed management practices revealed significant differences on the dry matter accumulation in leaves among various treatments recorded at all the growth stages (Table 17).

At 30 DAS, weed free check recorded significantly higher dry matter accumulation in leaves ($3.81 \text{ g plant}^{-1}$) as compared to weedy check (T_{10}) ($2.87 \text{ g plant}^{-1}$) and was on par with rest of treatment. Among herbicidal treatment (T_1 to T_7), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2, 4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_4) ($3.50 \text{ g plant}^{-1}$) recorded higher dry matter accumulation in leaves as compared to others.

At 60 DAS, higher dry matter accumulation in leaves was significantly higher in weed free check (T_9) ($11.50 \text{ g plant}^{-1}$) as compared to atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} (T_5) ($9.33 \text{ g plant}^{-1}$), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} (T_6) ($9.00 \text{ g plant}^{-1}$) and weedy check (T_{10}) ($8.72 \text{ g plant}^{-1}$) and was on par with rest of weed management practices. Among herbicidal treatment (T_1 to T_7), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2, 4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_4) recorded higher dry matter accumulation in leaves ($11.45 \text{ g plant}^{-1}$) as compared to others.

Same trend as that of 60 DAS was observed at 90 DAS.

Table 15: Leaf area (dm² plant⁻¹) of *kharif* sorghum as influenced by weed management practices

Treatments		Leaf area (dm ² plant ⁻¹)		
		30 DAS	60 DAS	90 DAS
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	12.15	29.74	26.13
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	11.93	31.09	25.13
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	12.41	30.10	26.61
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	13.13	31.84	26.77
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	11.76	25.11	23.88
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	11.96	18.31	17.96
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	11.74	31.19	25.11
T ₈	Farmers practice (1 HW fb 2 IC)	11.09	28.33	25.27
T ₉	Weed free check	13.18	32.51	28.21
T ₁₀	Weedy check	9.50	14.00	10.93
Mean		11.88	27.12	23.6
S.Em.±		0.54	1.41	1.36
CD (P = 0.05)		1.61	4.20	4.03

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 16: Leaf area index of *kharif* sorghum as influenced by weed management practices

Treatments		Leaf area index		
		30 DAS	60 DAS	90 DAS
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	1.80	4.41	3.87
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	1.74	4.61	3.74
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	1.84	4.47	3.94
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	1.95	4.72	3.97
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	1.72	3.68	3.30
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	1.79	2.71	2.51
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	1.77	4.46	3.72
T ₈	Farmers practice (1 HW fb 2 IC)	1.64	4.40	3.72
T ₉	Weed free check	1.95	4.82	4.18
T ₁₀	Weedy check	1.41	2.07	1.62
Mean		1.73	4.03	3.46
S.Em.±		0.08	0.15	0.19
CD (P = 0.05)		0.24	0.43	0.57

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

At harvest, dry matter accumulation in leaves was significantly higher in weed free check (T₉) (14.61 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (10.89 g plant⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (10.33 g plant⁻¹) and weedy check (T₁₀) (7.28 g plant⁻¹) and was on par with rest of weed management practices. Among herbicidal treatment (T₁ to T₇), all treatments were on par with each other in recording dry matter accumulation in leaves.

4.2.5 Dry matter accumulation in stem (g plant⁻¹)

The dry matter accumulation of sorghum in stem differed significantly due to various integrated weed management practices at all the growth stages (Table 18).

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃), weed free check (T₉) recorded significantly higher dry matter accumulation in stem (1.67 g plant⁻¹) as compared to T₁₀ (1.23 g plant⁻¹) and was on par with rest of treatments.

At 60 DAS, dry matter accumulation in stems was significantly with weed free check (T₉) (27.10 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (22.00 g plant⁻¹) atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (18.32 g plant⁻¹), weedy check (T₁₀) (16.88 g plant⁻¹) and was on par with rest of treatment. Among herbicidal treatment (T₁ to T₇), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded higher dry matter accumulation in stem (26.32 g plant⁻¹) as compared to others.

At 90 DAS, weed free check (T₉) recorded significantly higher dry matter accumulation in stem (49.89) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T₁), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (39.56 g plant⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (39.44 g plant⁻¹), weedy check (T₁₀) (28.89) and was on par with rest of the weed management practices. Among the herbicidal treatments (T₁ to T₇), dry matter accumulation in stem was significantly higher in atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T₁), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) which was on par with rest of treatments.

At harvest, dry matter accumulation in stem was significantly higher with weed free check (T₉) (51.55 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (43.56 g plant⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (37.78 g plant⁻¹), weedy check (T₁₀) (34.22 g plant⁻¹) and was on par other weed management practices. Among the herbicidal treatments (T₁ to T₇), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (49.11 g plant⁻¹) recorded significantly higher, dry matter accumulation in stem as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) which was on par with rest of the treatments.

4.2.6 Dry matter accumulation in ear (g plant⁻¹)

The dry matter accumulation in ear was significantly influenced by various integrated weed management practices at all the stages (Table 19). Weedy check recorded significantly lower dry matter accumulation in ear at 60 DAS (5.87 g plant⁻¹), 90 DAS (39.22 g plant⁻¹) and at harvest (90.89 g plant⁻¹) as compared to other treatments.

At 60 DAS, weed free check (T₉) recorded significantly higher dry matter accumulation in ear (13.72 g plant⁻¹) compared atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (9.22 g plant⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (9.00 g plant⁻¹), weedy check (T₁₀) (5.87 g plant⁻¹) and was on par with rest of the treatments. Among the herbicidal treatments (T₁ to T₇), dry matter accumulation in ear was higher in of atrazine @ 0.5 kg a.i. ha⁻¹ of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (12.85 g plant⁻¹) as compared to others.

At 90 DAS, weed free check (T₉) recorded significantly higher dry matter accumulation in ear (82.78 g plant⁻¹) as compared to other weed management practices except atrazine @ 0.5 kg a.i. ha⁻¹ of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (78.89 g plant⁻¹) with which it was on par.

Table 17: Dry matter accumulation in leaves (g plant⁻¹) of *Kharif* sorghum at different growth stages as influenced by weed management practices

Treatments		Dry matter accumulation in leaves (g plant ⁻¹)			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	3.43	11.11	14.83	11.83
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	3.43	11.33	15.28	12.39
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	3.43	11.39	15.67	12.67
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	3.50	11.45	16.22	13.06
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	3.33	9.33	11.89	10.89
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	3.37	9.00	11.78	10.33
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	3.43	11.22	14.89	11.95
T ₈	Farmers practice (1 HW fb 2 IC)	3.43	10.25	14.83	11.60
T ₉	Weed free check	3.81	11.50	17.56	14.61
T ₁₀	Weedy check	2.87	8.72	11.34	7.28
Mean		3.38	10.51	14.42	11.66
S.Em.±		0.17	0.42	0.94	1.02
CD (P = 0.05)		0.51	1.26	2.78	3.02

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 18: Dry matter accumulation in stem (g plant⁻¹) of *Kharif* sorghum at as influenced weed management practices

Treatments		Dry matter accumulation in stems (g plant ⁻¹)			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	1.43	25.30	42.45	45.89
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	1.57	25.26	47.89	46.22
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	1.67	25.9	47.78	48.11
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	1.67	26.32	48.56	49.11
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	1.44	22.00	39.56	43.56
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	1.45	18.32	39.44	37.78
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	1.59	25.05	45.66	46.11
T ₈	Farmers practice (1 HW fb 2 IC)	1.44	25.33	45.36	45.89
T ₉	Weed free check	1.67	27.10	49.89	51.55
T ₁₀	Weedy check	1.23	16.88	28.89	34.22
Mean		1.52	23.69	43.55	44.84
S.Em.±		0.08	0.75	1.62	2.22
CD (P = 0.05)		0.25	2.22	4.81	6.59

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 19: Dry matter accumulation in ear (g plant⁻¹) of *Kharif* sorghum as influenced by weed management practices

Treatments		Dry matter accumulation in ear (g plant ⁻¹)		
		60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	12.44	73.78	104.26
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	12.19	73.89	105.00
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	12.34	75.55	106.11
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	12.85	78.89	109.56
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	9.22	66.22	93.89
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	9.00	58.33	93.00
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	12.48	74.78	104.67
T ₈	Farmers practice (1 HW fb 2 IC)	12.21	73.11	102.74
T ₉	Weed free check	13.72	82.78	117.11
T ₁₀	Weedy check	5.87	39.22	90.89
Mean		11.23	69.66	102.72
S.Em.±		0.54	2.35	4.86
CD (P = 0.05)		1.61	6.99	14.43

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Among the herbicidal treatments (T_1 to T_7), dry matter accumulation in ear was significantly higher in atrazine @ 0.5 kg a.i.ha⁻¹ of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (66.22 g plant⁻¹), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (58.33 g plant⁻¹) and was on par with rest of treatments.

At harvest, weed free check (T_9) recorded significantly higher dry matter accumulation in ear (117.11 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (93.89 g plant⁻¹), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (93.00 g plant⁻¹), weedy check (T_{10}) (90.89 g plant⁻¹) and was on par with rest of treatments. Among herbicidal treatments (T_1 to T_7), atrazine @ 0.5 kg a.i.ha⁻¹ of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded higher dry matter accumulation in ear (109.56 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) and was on par with rest of treatments.

4.2.7 Total dry matter production of sorghum (TDMP) (g plant⁻¹)

The total dry matter production in sorghum recorded at 30, 60, 90 DAS and harvest was significantly influenced by various weed control treatments (Table 20).

Weedy check recorded significantly lower dry matter production of sorghum at 30 DAS (4.10 g plant⁻¹) and 90 DAS (79.45 g plant⁻¹) as compared to other treatments.

At 30 DAS, weed free check (T_9) recorded significantly higher total dry matter production in sorghum (5.48 g plant⁻¹) as compared to farmers practice (T_8) (4.77 g plant⁻¹) and weedy check (T_{10}) (4.10 g plant⁻¹) and was on par with rest of treatment. Among herbicidal treatment (T_1 to T_7), total dry matter production was higher in atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (5.17 g plant⁻¹) as compared to others.

At 60 DAS, weed free check (T_9) recorded significantly higher total dry matter production (52.32) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (40.56 g plant⁻¹), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (36.32 g plant⁻¹), weedy check (T_{10}) (31.47) and was on par with treatments. Among herbicidal treatment (T_1 to T_7), atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded significantly higher total dry matter production of sorghum (50.62 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) atrazine @ 0.5 kg a.i.ha⁻¹fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) and was on par with other treatments.

At 90 DAS, weed free check recorded significantly higher total dry matter production (150.22 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i.ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T_1), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6), farmers practice (T_8), weedy check (T_{10}) and was on par with rest of the weed management practices. Among herbicidal treatment (T_1 to T_7), total dry matter production was significantly higher in atrazine @ 0.5 kg a.i.ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (143.67 g plant⁻¹) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) and was par with rest of the treatments.

Same trend as that of 90 DAS was noticed at harvest.

4.3 Yield components of sorghum

The observations on grain weight per ear (g), ear length (cm), test weight (g), grain yield (q/ha), stover yield (t/ha), harvest index (%) and weed index are presented in Table 21.

4.3.1 Grain weight per ear (g)

Grain weight per ear (g) differed significantly due to various weed management practices (Table 21).

Among the various weed management practices, weed free check recorded significantly higher grain weight per ear (T_9) (30.44 g) as compared to pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (24.15 g), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (24.60 g), weedy check (24.16 g) and was on par with rest of the treatments.

Table 20: Total Dry matter production in *Kharif* sorghum (g plant⁻¹) as influenced by weed management practices

Treatments		Total Dry matter production			
		30 DAS	60 DAS	90 DAS	At harvest
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	4.86	48.85	131.06	161.99
T ₂	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	5.00	48.78	137.06	163.61
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	5.10	49.63	139.00	166.89
T ₄	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	5.17	50.62	143.67	171.72
T ₅	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	4.87	40.56	117.67	148.34
T ₆	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	4.82	36.32	109.55	141.11
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	5.03	48.75	135.33	162.73
T ₈	Farmers practice (1 HW fb 2 IC)	4.77	47.79	133.3	160.24
T ₉	Weed free check	5.48	52.32	150.22	183.28
T ₁₀	Weedy check	4.10	31.47	79.45	132.38
Mean		4.92	45.51	127.63	158.41
S.Em.±		0.22	2.16	5.22	6.78
CD (P = 0.05)		0.66	6.40	15.50	20.14

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Among herbicidal treatments (T_1 to T_7), Atrazine @ 0.5 kg a.i.ha⁻¹fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (30.36 g) as compared to others.

4.3.2 Ear length (cm)

Different weed management practices showed significant effect on ear length. Ear length of sorghum was significantly higher in weed free check (T_9) (28.8 cm) as compared to, atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (26.2 cm), weedy check (21.3 cm) and was on par with rest of treatments. Among herbicidal treatment (T_1 to T_7), Atrazine @ 0.5 kg a.i.ha⁻¹(PRE) fb 2, 4-D @ 0.75 kg a.i. ha⁻¹(T_4) (28.2 cm) as compared to other weed management practices.

4.3.3 Test weight (g)

Test weight differed significantly due to various weed management practices weed free check (T_9) recorded significantly higher test weight (31.43 g) compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (29.06 g), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (28.74 g), weedy check (27.64 g) and was on par with rest of the treatments. Among herbicidal treatment (T_1 to T_7), higher test weight was recorded with pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (30.38 g) as compared to other weed management practices.

4.3.4 Grain yield (q/ha)

Grain yield was significantly influenced by the various weed management practices weed free check (T_9) recorded significantly higher grain yield (45.52 q/ha) as compared to pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (37.48 q/ha), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (34.11 q/ha), weedy check (31.62 q/ha) and was on par with rest of the treatments. Among herbicidal treatment (T_1 to T_7), pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded higher grain yield (44.24 q/ha) as compared to other weed management practices.

4.3.5 Stover yield (t/ha)

Different weed management practices show significant effect on stover yield. Weed free check (T_9) recorded significantly higher stover yield (10.46 t/ha) as compared to pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb Post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (7.88 t/ha), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T_6) (6.95 t/ha), atrazine @ 0.5 kg a.i. ha⁻¹ +1 HW+ 2 IC (T_7) (9.32), weedy check (T_{10}) (7.62 t/ha) and was on par with rest of the treatments. Among herbicidal treatment (T_1 to T_7), higher stover yield was recorded in atrazine @ 0.5 kg a.i.ha⁻¹ fb Post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (9.83 t/ha) as compared to other weed management practices.

4.3.6 Harvest index (%)

Harvest did not differ significantly due to various weed management practices (Table 21).

4.3.7 Weed index (%)

Weed index was significantly higher in weedy check (T_9) (30.52 %) as compared to others. Among the herbicidal treatments (T_1 to T_7), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T_5) (25.03) recorded significantly higher as compared to others weed management practices. While weed index was significantly lower in atrazine @ 0.5 kg a.i.ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T_4) (2.79 %) as compared to other weed management practices except atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) + 1HW+2 IC (T_7) (4.86 %) which was on par.

4.3.8 Nutrient uptake by sorghum (kg/ha)

Various weed management practices showed significantly effect on nutrient uptake by sorghum at 60 DAS and harvest (Table 22). Weedy check recorded lower NPK uptake as compared to other treatments. Similarly higher NPK uptake was recorded in weed free check compared to other weed management practices both at 60 DAS and harvest.

Table 21: Yield and yield components of *Kharif* sorghum as influenced by weed management practices

Treatments		Grain weight per ear (g)	Ear length (cm)	Test weight (g)	Grain yield (q/ha)	Stover yield (t/ha)	Harvest index (%)	Weed index (%)
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	29.32	27.4	31.04	41.58	9.45	30.55	8.62
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	29.29	27.9	30.52	42.12	9.83	30.00	7.47
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	30.22	28.1	30.02	42.27	9.83	30.15	7.13
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	30.36	28.2	30.38	44.24	9.83	31.02	2.79
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	24.15	26.6	29.06	37.48	7.88	31.60	20.49
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	24.60	26.2	28.74	34.11	6.95	32.92	25.03
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	30.29	27.5	30.23	43.30	9.32	31.71	4.86
T ₈	Farmers practice (1 HW fb 2 IC)	29.41	27.1	30.04	41.58	9.45	30.54	8.68
T ₉	Weed free check	30.44	28.8	31.43	45.52	10.46	30.36	0.00
T ₁₀	Weedy check	24.16	21.3	27.64	31.62	7.62	29.39	30.52
Mean		28.62	26.89	29.91	40.71	9.06	30.84	11.56
S.Em.±		1.49	0.83	0.73	1.66	0.38	1.29	1.38
CD (P = 0.05)		4.43	2.46	2.17	4.94	1.13	NS	4.09

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 22: Nutrient uptake (kg/ha) by *Kharif* sorghum as influenced by weed management practices

Treatments		60 DAS			At harvest		
		N	P	K	N	P	K
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	112.39	13.45	143.60	95.41	17.95	136.98
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	115.76	15.40	148.56	107.11	20.64	134.63
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	116.90	15.68	152.13	109.08	20.78	142.49
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	119.62	16.99	152.63	109.08	24.57	142.49
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	71.95	11.87	105.81	75.06	13.72	106.43
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	105.48	12.70	116.35	91.63	15.68	100.78
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	113.95	13.52	147.90	104.42	17.71	137.99
T ₈	Farmers practice (1 HW fb 2 IC)	116.33	13.03	138.15	92.24	16.56	131.31
T ₉	Weed free check	122.62	17.84	163.69	115.02	24.57	146.38
T ₁₀	Weedy check	59.10	9.16	86.49	65.56	13.21	102.92
Mean		100.55	13.96	135.53	96.46	18.54	128.24
S.Em.±		2.75	1.13	6.69	4.02	0.79	5.32
CD (P = 0.05)		8.17	3.37	19.89	11.94	2.33	15.82

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Nitrogen

At 60 DAS, among the various weed management practices (T_1 to T_7) pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded significantly higher nitrogen uptake (119.62 kg/ha) compared to pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (71.95 kg/ha), pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹fb post-emergence application of metsulfuron methyl @ 6 g a.i. ha⁻¹ (105.48 kg/ha) and was on par with rest of the treatments.

At harvest, among the various weed management practices (T_1 to T_7) atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.5 kg a.i. ha⁻¹ (152.13 kg/ha) recorded significantly higher nitrogen uptake compared to pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ (17.95 kg/ha), pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of metsulfuron methyl @ 4 g a.i. ha⁻¹ (75.06 kg/ha), pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹fb post-emergence application of metsulfuron methyl @ 6 g a.i. ha⁻¹ (POST) (91.63 kg/ha), farmers practice (92.24 kg/ha) and was on par with rest of the treatments.

Phosphorous

At 60 DAS, among the various weed management practices (T_1 to T_7), pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded significantly higher phosphorous uptake (16.99 kg/ha) compared to atrazine @ 0.5 kg a.i.ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (13.45 kg/ha), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (11.87 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (12.70 kg/ha) and was on par with rest of the treatments.

Potassium

At 60 DAS among the various weed management practices (T_1 to T_7) pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T_4) recorded significantly higher potassium uptake (152.63 kg/ha) compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (105.81 kg/ha), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (116.35 kg /ha) and was on par with rest of the treatments.

Similar trend was observed at harvest.

4.4.9 Available N, P₂O₅ and K₂O in soil

The observations on available N, P₂O₅ and K₂O in soil as influenced by different weed management practices are presented in Table. 23.

Various weed management practices did influence available N, P₂O₅ and K₂O significantly at harvest. However, pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ (T_1) had higher available nitrogen (187.07 kg/ha), weed free check (T_9) had higher available P₂O₅ (23.76 kg/ha) and K₂O (333.20 kg/ha) as compared to other weed management practices.

4.4 Economics

The data on cost of cultivation, gross returns, net returns and benefit cost ratio (B: C) as influenced by various weed control treatments are presented in Table 24 and economic details are provided in Appendix I and II.

4.4.1 Cost of cultivation (₹/ha)

The higher cost of cultivation was realized in weed free check (T_9) (₹ 25,965 ha⁻¹) and the lower cost of cultivation was noticed in weedy check (T_{10}) (₹ 19,065 ha⁻¹) as compared to other weed management practices.

Table 23: Available N, P₂O₅ and K₂O (kg ha⁻¹) in soil after harvest of *Kharif* sorghum as influenced by weed management practices

Treatments		After harvest		
		N	P ₂ O ₅	K ₂ O
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	187.07	22.75	301.04
T ₂	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	167.80	22.92	327.24
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	165.20	23.54	312.57
T ₄	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	170.14	23.64	323.60
T ₅	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	179.11	22.52	307.14
T ₆	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	181.44	21.99	300.78
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	172.17	22.52	326.33
T ₈	Farmers practice (1 HW fb 2 IC)	184.34	22.29	316.00
T ₉	Weed free check	167.67	23.76	333.20
T ₁₀	Weedy check	162.40	20.95	299.58
Mean		173.73	22.65	314.75
S.Em.±		3.47	1.54	8.20
CD (P = 0.05)		NS	NS	NS

DAS= Days after sowing, PRE=Pre-emergence, POST=Post-emergence, fb= followed by, IC= Intercultivation, HW= Hand weeding, RPP= Recommended package of practice

Table 24: Economics of *Kharif* sorghum as influenced by different weed management practices

Treatments		Cost of cultivation (₹/ha)	Gross Returns (₹/ha)	Net Returns (₹/ha)	B:C ratio
T ₁	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha ⁻¹ (POST)	20705	47476	26771	2.29
T ₂	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha ⁻¹ (POST)	20865	48393	27528	2.32
T ₃	Atrazine @ 0.5 kg a.i. ha ⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha ⁻¹ (POST)	20540	47941	27401	2.33
T ₄	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha ⁻¹ (POST)	20610	50139	29529	2.43
T ₅	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹ (POST)	20413	41864	21451	2.05
T ₆	Atrazine @ 0.5 kg a.i.ha ⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹ (POST)	20427	39476	19049	1.93
T ₇	Atrazine @0.5 kg a.i. ha ⁻¹ (PRE) + 1HW+2 IC (Check-RPP)	21685	48595	26910	2.24
T ₈	Farmers practice (1 HW fb 2 IC)	21165	47476	26311	2.24
T ₉	Weed free check	25965	51117	25152	1.97
T ₁₀	Weedy check	19065	37602	18537	1.97
SEm±		-	1598	1598	0.08
CD (P = 0.05)		-	4748	4748	0.23

DAS - Days after sowing, IC – Intercultivation, HW - Hand weeding

Table 25: Correlation between grain yield (q/ha) with various crop and weed parameters

Sl. No	Growth parameters of <i>Kharif</i> sorghum	Correlation coefficient (r)
1	Plant height (cm) at 30 DAS	0.87*
2	Plant height (cm) at 60 DAS	0.97*
3	Plant height (cm) at 90 DAS	0.94*
4	Plant height (cm) at harvest	0.94*
5	Leaf area at 30 DAS	0.90*
6	Leaf area at 60 DAS	0.98*
7	Leaf area at 90 DAS	0.94*
8	Leaf area index at 30 DAS	0.92*
9	Leaf area index at 60 DAS	0.98*
10	Leaf area index at 90 DAS	0.96*
11	Total dry matter production at 30 DAS	0.85*
12	Total dry matter production at 60 DAS	0.99*
13	Total dry matter production at 90 DAS	0.97*
14	Total dry matter production at harvest	0.97*
	Yield parameters of <i>Kharif</i> sorghum	
1	Grain weight per ear (g)	0.93*
2	Ear length (cm)	0.88*
3	Test weight (g)	0.93*
4	Stover yield (t/ha)	0.93*
5	Harvest index (%)	-0.15*
6	Weed index (%)	-1.00*
	Uptake of nutrients by crop	
1	Nitrogen at 60 DAS	0.83*
2	Nitrogen at Harvest	0.87*
3	Phosphorous at 60 DAS	0.86*
4	Phosphorous at harvest	0.82*
5	Potassium at 60 DAS	0.95*
6	Potassium at harvest	0.95*

Contd...

	Weed parameters of sorghum	
1	Weed count at 30 DAS	-0.65*
2	Weed count at 60 DAS	-0.79*
3	Weed count at 90 DAS	-0.79*
4	Weed count at harvest	-0.78*
5	Total dry weight of weeds (30 DAS)	-0.63*
6	Total dry weight of weeds (60 DAS)	-0.81*
7	Total dry weight of weeds(90 DAS)	-0.77*
8	Total dry weight of weeds (At harvest)	-0.86*
9	Weed control efficiency (30 DAS)	0.64*
10	Weed control efficiency (60 DAS)	0.81*
11	Weed control efficiency (90 DAS)	0.77*
12	Weed control efficiency (harvest)	0.86*
13	Nitrogen uptake at 60 DAS	-0.71*
14	Nitrogen uptake at harvest	-0.71*
15	Phosphorous uptake at 60 DAS	-0.79*
16	Phosphorous uptake at harvest	-0.74*
17	Potassium uptake at 60 DAS	-0.79*
18	Potassium uptake at harvest	-0.87*

* Significance at 5% level of significance

4.4.2 Gross returns (₹/ha)

Gross returns differed significantly due to different weed control treatments. Weed free realized significantly higher gross return (51,117 ₹/ha) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹(T₅), atrazine @ 0.5 kg a.i. ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹(T₆), weedy check (T₁₀) was on par with rest of treatment. Among herbicidal treatment (T₁ to T₇) gross returns were significantly higher pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (₹ 50,139.33 ha⁻¹) compared to atrazine @ 0.5 kg a.i. ha⁻¹ metsulfuron methyl @ 4 g a.i. ha⁻¹, atrazine @ 0.5 kg a.i. ha⁻¹ metsulfuron methyl @ 6 g a.i. ha⁻¹ and was on par with rest of the treatments.

4.4.3 Net returns (₹/ha)

The various weed management practices had significant effect on net returns. Net returns were significantly higher in pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (₹ 29,529 ha⁻¹) compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹(T₅) (₹ 21,451 ha⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹(PRE) fb metsulfuron methyl @ 6 g a.i. ha⁻¹(T₆) (₹ 19,049 ha⁻¹), weedy check (T₁₀) (₹ 18,537/ha) and was on par with rest of the treatments.

4.4.4 Benefit cost ratio (B: C)

Benefit cost ratio differed significantly due to various weed control treatments.

Benefit cost ratio were significantly higher pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹fb post-emergence application of 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (2.43) as compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (2.05), atrazine @ 0.5 kg a.i.ha⁻¹fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (1.93) and was on par with rest of the treatments.

4.5 Correlation studies

Significant and positive correlation was observed between sorghum grain yield and growth and yield parameters (Table 25). At harvest, growth parameters such as plant height (r=0.94), leaf area plant⁻¹ (r=0.98), leaf area index, total dry matter production (r=0.97) were significantly and positively correlated with grain yield. Similarly between grain yield and yield components such as grain weight per ear (r= 0.93), ear length (r= 0.88) and test weight (r=0.93).

Weed density, total dry weight of weeds and nutrient uptake at all the growth stages were significantly and correlated with grain yield. While the weed control efficiency positively and significantly correlated with grain yield at all the growth stages.

Sorghum grain yield showed negatively correlation with weed dry weight (r=0.86), weed index (r=1.00), weed population per m² (r=0.78), nutrient uptake by the weeds and positively correlated with weed control efficiency (r=0.86).

5. DISCUSSION

Weed competition with crop plants is one the important factor limiting the crop yields. In sorghum, weed competition starts from three to six weeks after crop emergence. Although weeds can be controlled effectively by cultural methods, yet these are time consuming, laborious, expensive and are often not possible to practice on large scale on account of adverse weather and soil conditions, availability of labours etc. Even though the herbicides viz, atrazine, 2, 4-D, etc have been recommended in sorghum, some newer herbicides need to be tried for their efficacy on weed control and their effect on crop growth, yield and economics. Hence, the present experiment was undertaken to study the integrated weed management practices in *kharif* sorghum. The results have been discussed under the following major aspects.

5.1 Weather and climate on crop growth

Crop growth mainly depends on environmental factors. Fluctuations in weather condition greatly influence the growth, development and thereby yielding ability of the crop. The availability of water in adequate quantity over the ontogeny of crop is most essential for successful crop production and that too under rain fed condition where the water is a limiting factor. Thus, the adequate quantity and uniform distribution of rainfall forms an important factor in periodical replenishment of soil moisture to sustain crop growth.

The total annual rainfall received during 2011 was 922.7 mm distributed in 72 rainy days (Table 2 and Fig.1). The rainfall during cropping period (June-Sept) was 532 mm which was well distributed during crop growth period. The sorghum seeds were sown on 14-06-2011 with sufficient stored soil moisture conditions. The rainfall received in the month of June (194 mm) and July (131 mm) ensured adequate stored moisture for germination, emergence and early establishment of seedlings. Further the adequate quantity and uniform distribution of rainfall during August, September ensured proper growth and development of sorghum. Higher rainfall was received in the month of June (86.49 mm) (compared to normal) encouraged the vigorous growth of weeds. The rainfall during cropping season was much higher than normal and was well distributed. This resulted in good growth and development of crop. The mean maximum temperature during the period of experimentation was ranged from 26.2°C (August) to 29.9°C (October), while the minimum temperature was ranged from 19.5°C (October) to 21.3°C (June). Both minimum and maximum temperatures were favourable for normal growth and development of crop. The mean relative humidity varied from 73 per cent in the month of October to 87 per cent in the month of August 2011.

5.2 Weed flora

The weed flora noticed in the experimental site comprised of grasses, sedges and broad leaved weeds (Table 4). The important grassy weeds observed were *Cynodon dactylon*, *Digitaria sanguinalis*, *Dinebra retroflexa* and *Echinochloa colona*. *Cyperus rotundus* was lone weed under sedge category. Among broad leaved weeds *Ageratum conyzoides* L., *Amaranthus viridis*, *Amaranthus spinosus*, *Commelina benghalensis*, *Cyanotis cucullata*, *Phyllanthus niruri* and *Mollugo verticillata* L. were the dominant weeds.

Various authors (Murthy, 1950; Krishnasastry, 1957; Verma and Bharadwaj 1963; Upadhyay *et al.*, 1981; Shetty, 1979; Sharma, 1981; Latchanna, 1983;) reported different weed flora in sorghum. The weed flora in general varies with type of soil, growing season from place to place. Murthy (1957) and Sharanappa (1980) observed 10 monocots and 29 dicot weeds in *kharif* sorghum grown in black soil of Dharwad.

Mahendra Singh *et al.* (1973) observed *Trianthema monogyna* as predominant weed followed by *Digera arvensis*, *Cyperus rotundus* and *Cynodon dactylon* till harvest of grain sorghum in New Delhi. Sharma *et al.* (2000b) reported that Rajasthan, the predominant weeds observed in sorghum crop were *Commelina benghalensis* L., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Digera arvensis* Forsk., *Echinochloa colona* (L.) Link., *Eclipta alba* (L.) Hassk., *Phyllanthus niruri* Hookf., *Solanum nigrum* L., *Sorghum halepense* (L.) Pers. and *Trianthema portulacastrum* L. Soundari and Kathiresan (2002) reported that weed flora like *Trianthema portulacastrum* L., *Eclipta alba* L., *Cyperus rotundus* L. and *Cynodon dactylon* (L.) Pers were observed in sorghum experimental field in Tamil Nadu. Rao *et al.* (2007)

reported that dominating weeds in sorghum were *Digeria muricata* (L.) Mart. Syn. *Digeria arvensis* Forsk., *Amaranthus spinosus* L., *Amaranthus viridis* L., *Trianthema portulacastrum* L., *Euphorbia hirta* L., *Tribulus terrestris* L. among the broad-leaf weeds; *Setaria glauca* L., *Digiteria sanguinalis* (L.) Scop. *Dactyloctenium aegyptium* (L.) Willd. and *Panicum repens* L. (grassy weeds) and *Cyperus rotundus* L. (sedges). Among them, *D. arvensis*, *A. spinosus* and *A. viridis* were the most predominant weed species with the average density of 30, 25 and 15%, respectively in Rajasthan.

5.3 Weed control rating

Visual observations on weed control rating showed marked differences among the different weed control treatments (Table 9). The pre-emergence application of herbicides (T₁, T₂, T₃, T₄, T₅, T₆ and T₇) recorded good to excellent control of weeds at 7, 14 and 21 DAS. The weed control rating observed after post-emergence application of herbicides revealed good control of weeds. Atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) and atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) treated plots at 7 days after spray. The treatments viz; T₂, T₁, T₅, T₆ and T₉ recorded good control of weeds. At subsequent stages i.e. 14 and 21 days after spray of herbicide, all the herbicide treatments plots recorded satisfactory to excellent control of weeds (i.e. 6 to 9 on 10 point scale).

5.4 Crop toxicity rating as influenced by pre and post-emergence application of herbicides

The crop toxicity rating observed at 7, 14 and 21 days after pre-emergence herbicide application had no injury on the crop growth and the crop growth was normal (Table 9). The earlier findings on atrazine (Kurdikeri, 1972), also revealed that these herbicides had no injury on the crop when used as pre-emergence.

The similar trend in crop phytotoxicity ratings was observed after post-emergence herbicides (7, 14 and 21 days after spray). In plots sprayed with atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 4 g a.i. ha⁻¹ (Plate 2) and atrazine @ 0.5 kg a.i. ha⁻¹ fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (Plate 3), there was slight discolouration (1.00-4.00 rating) of leaves and stems and some crop stand loss, stunting and discolouration at 7 and 14 days after spray of post-emergence herbicides. However, the crop recovered after 21 days. The results are in conformity with the findings of David *et al.* (2004) and Shane Hennigh *et al.* (2010).

5.5 Effect of integrated weed management practices on weed growth

Competition is the struggle for survival and continued existence. In plant communities, each individual is in a continuous state of war to gain in its competition for various growth factors both under-ground and above-ground. Competition occurs when two or all plants present in a given area demand a particular growth factor and the instantaneous supply of that factor falls below their combined demand. In a crop-weed ecosystem, the total effect of weed competition, which results from competition in various forms such as for nutrients, moisture, radiation, space, O₂ and CO₂ is reflected on the growth and yield of the crop (Zimdahl, 1999). The yield reductions are generally in proportion to the amount of light, water and nutrients used by weeds at the expense of a crop. A very general rule is that for every unit of weeds grown, there will be one less unit of crop grown.

The concept of critical period of weed competition might have originated from the belief that weeds are not equally damaging all through the growing period of a crop. The critical period of weed-crop competition is the shortest time span in the ontogeny of crop when weeding will result in the highest economic returns. The crop yield levels obtained by managing the weeds during this period should provide crop yield levels sufficiently close to those obtained by the full season freedom from weeds.

Unfortunately, most farmers erroneously assume that removing weeds any time during the growing season was good enough for obtaining full benefits of weeding in terms of increased crop yields. But contrary to it, substantial scientific evidences are now available which show beyond doubt that the time of weeding a crop is as important as the weeding itself. Fundamental principle of plant ecology is that early occupants of the ground tend to discourage or exclude the later ones.



Plate 2: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha⁻¹ (POST) (T₅) at 40 DAS



Plate 3: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (POST) (T₆) at 40 DAS

This holds good also in agriculture. The weeds that germinate either before or along the crop offer stronger competition to it than the later germinating ones. It has been observed that these early weeds accumulate dry matter faster than the crop seedlings. In sorghum, it has been found that during the initial period of two to three weeks after crop emergence, weeds complete about 15-18 per cent of their full season growth, while the crop plants accomplish only 2-3 per cent of it. Therefore, there is a need of early season weeding in most of the annual crops.

At all the stages of crop growth, weed density and total dry weight of weeds differed significantly and were significantly higher in weedy check (T_{10}) at 30, 60, 90 DAS and at harvest (Tables 8 and 10, Fig. 3 and 4). While weed free check recorded the lower values. This non interference of weed growth in weedy check resulted in maximum utilization of resources (moisture, nutrient, light and space) resulting in higher weed dry weight. The various earlier workers (Chopra and Angiras, 2008 and Rao *et al.*, 2009 in maize) also reported higher weed density and dry weight in weedy check. On the other hand, lower weed dry weight was noticed in weed free check. This could be attributed to control of weeds by cultural methods at regular intervals, which resulted in reduced weed density and dry matter production by weeds. These results are in conformity with the findings of Gupta and Singh, (1967), Intodia *et al.* (1996), Tripathi *et al.* (2005) and Nagalakshmi *et al.* (2006).

The data on total weed density per m^2 area differed significantly due to various weed management practices at all the growth stages. The higher weed density was (Plate 6) recorded in weedy check (10.67, 12.34, 13.19, 12.89 per m^2 at 30, 60, 90 DAS and at harvest, respectively), where as weed free check recorded the lower values (Plate 5). At 30 DAS, weed management practices like application of atrazine @ 0.5 kg a.i. ha^{-1} on the day of sowing or one day after sowing recorded better control of weeds (Sharma *et al.*, 2000), (Baker and Terry, 1991), (Mani and Chandhokar, 1965), (Hosmani *et al.* 1969), (Burnside and Wicks, 1964), (Robinson *et al.*, 1964), (Lyubenov, 1969), (Mahendra Singh *et al.*, 1973) but all most all weed species were observed in weedy check. From 30 DAS to harvest, good control of weeds was achieved with pre-emergence application of atrazine @ 0.5 kg a.i. ha^{-1} fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha^{-1} (T_4), atrazine @ 0.5 kg a.i. ha^{-1} fb 2, 4-D @ 0.5 kg a.i. ha^{-1} (T_3), atrazine @ 0.5 kg a.i. ha^{-1} fb atrazine @ 0.75 kg a.i. ha^{-1} (T_2), atrazine @ 0.5 kg a.i. ha^{-1} fb atrazine @ 0.5 kg a.i. ha^{-1} (T_1), atrazine @ 0.5 kg a.i. ha^{-1} + 1HW+2 IC (T_7). But in weedy check, high density of weeds interfered the harvesting of sorghum. It was mainly due to uninterrupted growth of weeds which made best use of growth resources (Patel *et al.*, 2000). Similar results are reported by Paradkar and Sharma, (1993), Sreenivas and Satyanarayana, (1994) and Ramesh and Nadanssababady, (2005)

Weed free check which received hand weeding at regular intervals indicated that complete weed control was possible only by local methods (hand weeding). However, this will neither economical nor possible under scarcity of labour on large areas. This is in conformity with the findings of Kolage *et al.* (2004) and Patel *et al.* (2006).

The data on total weed density (Tables 5,6,7,8) per m^2 area indicated that among weed management practices, pre-emergence application of atrazine @ 0.5 kg a.i. ha^{-1} fb post-emergence application 2, 4-D @ 0.75 kg a.i. ha^{-1} or 2, 4-D @ 0.5 kg a.i. ha^{-1} after sowing recorded excellent control of weeds (grasses, sedges and broad-leaved weeds) during initial stages of crop growth (Mahendra Singh *et al.*, 1973) (Rout and Satapathy, 1996 and Kolage *et al.*, 2004). In farmer's practice, weed population was significantly higher during initial stages. This was due to ineffective intercultivation at 20 DAS due to continuous and heavy rainfall which lead to inefficient control of weeds. At 30 DAS, weed population was controlled by one hand weeding but it increased upto harvest. This was mainly attributed to heavy and continuous rainfall which led to vigorous growth of weeds due to availability of sufficient soil moisture. These results corroborated with the findings of Ramesh and Nadanssababady (2005) and Kamble *et al.* (2005). Application of 2, 4-D (0.75 kg a.i. ha^{-1}) as a post-emergence application recorded effective control of broad leaved weeds (Gaur *et al.*, 1991, Dakshindas, 1961 and Hosmani *et al.*, 1969) and satisfactory control of grasses and sedges (Paradkar and Sharma, 1993; Sreenivas and Satyanarayana, 1994 and Ramesh and Nadanssababady, 2005). Reduction in the weed density was also reported by application of atrazine as post-emergence herbicides, at 60 DAS application of atrazine @ 0.5 kg a.i. ha^{-1} fb atrazine @ 0.75 kg a.i. ha^{-1} (2.31) recorded significantly lower number of grassy weeds as compared to T_4 (2.73). Similar observations were made by Shailendra Singh, (2011) in maize.



Plate 4: Weed free check at 60 DAS (T₉)



Plate 5: Weedy check at 60 DAS (T₁₀)

At 60 DAS, pre-emergent application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly lower dry weight of weeds / m² (1.87) which was on par with rest of the treatments. Pratap Singh and Mashiat Ali (2004) reported the similar results.

The total dry weight of weeds also differed significantly due to various weed control treatments (Table 11). At all crop growth stages, the higher total dry weight of weeds was recorded in weedy check (4.08, 4.67, 6.20 and 6.23 g / m² at 30, 60, 90 DAS and at harvest, respectively). It was mainly due to higher and uninterrupted growth of weeds viz., grasses, sedges, broad leaved and total weed population (10.67, 12.34, 13.19 and 12.89 weeds / m² at 30, 60, 90 DAS and at harvest respectively) which made better use of the growth resources. On the other hand, lower total dry weight of weeds was recorded in weed free check. This could be attributed to control of weeds by hand weeding fb intercultivation at regular intervals, which resulted in reduced dry matter production by weeds.

At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ recorded significantly lower dry weight of weeds / m² (2.15g per m²) as compared to other treatments except farmers practice (3.75g per m²) which were on a par. (Ramesh *et al.*, 2005, Upadhyay *et al.*, 1981 and Shantveerayya and Agasimani, 2012). It was mainly due to the lower population of broad-leaved weeds, grasses and sedges. These results are conformity with findings of Kannur (2008), Ramesh and Nadanssababady (2005) and Girma and Chinawong (2005). At 60 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ recorded significantly lower dry weight of weeds g / m² (1.87 g / m²) which was on par with rest of the treatments.

Performance of crop is directly proportional to the weed control efficiency (Table 12 and Fig. 5) and inversely proportional to the weed index. In the present study among the weed control treatments, higher weed control efficiency was recorded at all the crop growth stages. At 30 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher weed control efficiency (47.20 %) as compared to other treatments except atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (35.70 %), farmers practice (8.88 %) which were on par. It was due to higher weed population and total dry weight of weeds in this treatments. These results corroborate with the findings of Satao and Nalamwar (1992), Paradkar and Sharma (1993), Saini and Angiras (1998) Shiva dhar *et al.* (2006), Sreenivas and Satyanarayana (1994), Rao *et al.* (2007) and Shantveerayya and Agasimani (2012). At 60 DAS, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher weed control efficiency (60.66%) compared to weedy check and it was on par with rest of the treatments. The higher weed control efficiency in these treatments could be attributed to the lower weed population and total weed dry weight, Similar observations were made by Pratap Singh and Mashiat Ali (2004) and Sanjoy Saha and Rao (2010).

Weed index which is a measure of crop yield reduction due to weed competition. It was higher in weedy check (30.52 %) and on a par with atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (20.49 %), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (25.03 %) (Table 21). This was attributed to lower grain yield in weedy check due to greater competition offered by unchecked weed growth for nutrients, moisture, space and light as indicated by poor growth and yield components (Krishnamurthy *et al.*, 1981). The lower weed index (2.79 %) was recorded with application of (T₄) atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ and it was on par with atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.5 kg a.i. ha⁻¹ (T₁) (8.62), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (7.47), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (7.13), atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) + 1HW+2 IC (T₇) (4.86) and farmer practice (T₈) (8.68). This was mainly due to the higher sorghum grain yields in these treatments as a result of improved crop growth and effective control of weeds there by reduction in the crop-weed competition. These results are in conformity with results of Satao and Nalamwar (1992), Kannur (2008) and Kolage *et al.* (2004).

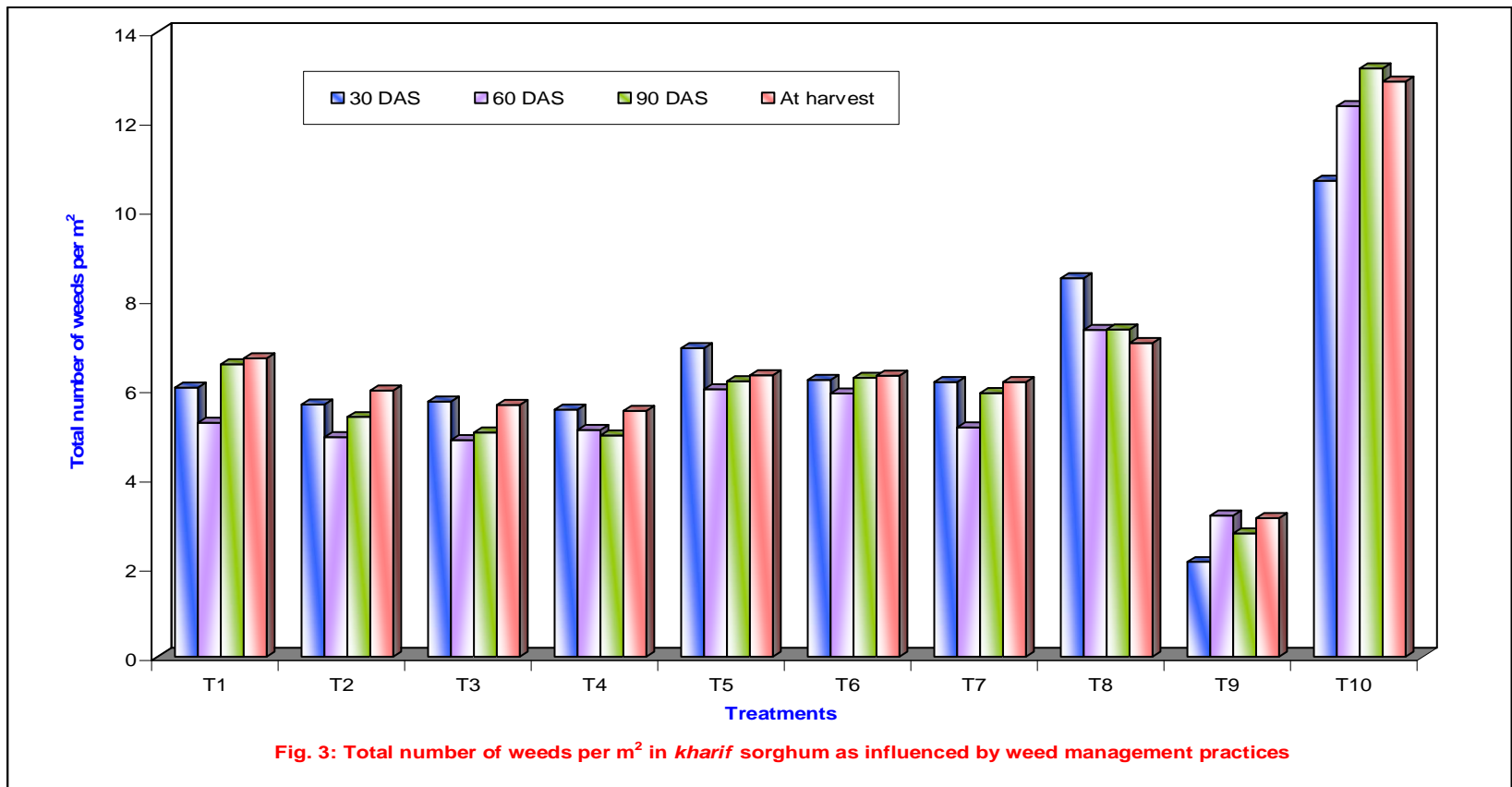


Fig. 3: Total number of weeds per m² in kharif sorghum as influenced by weed management practices

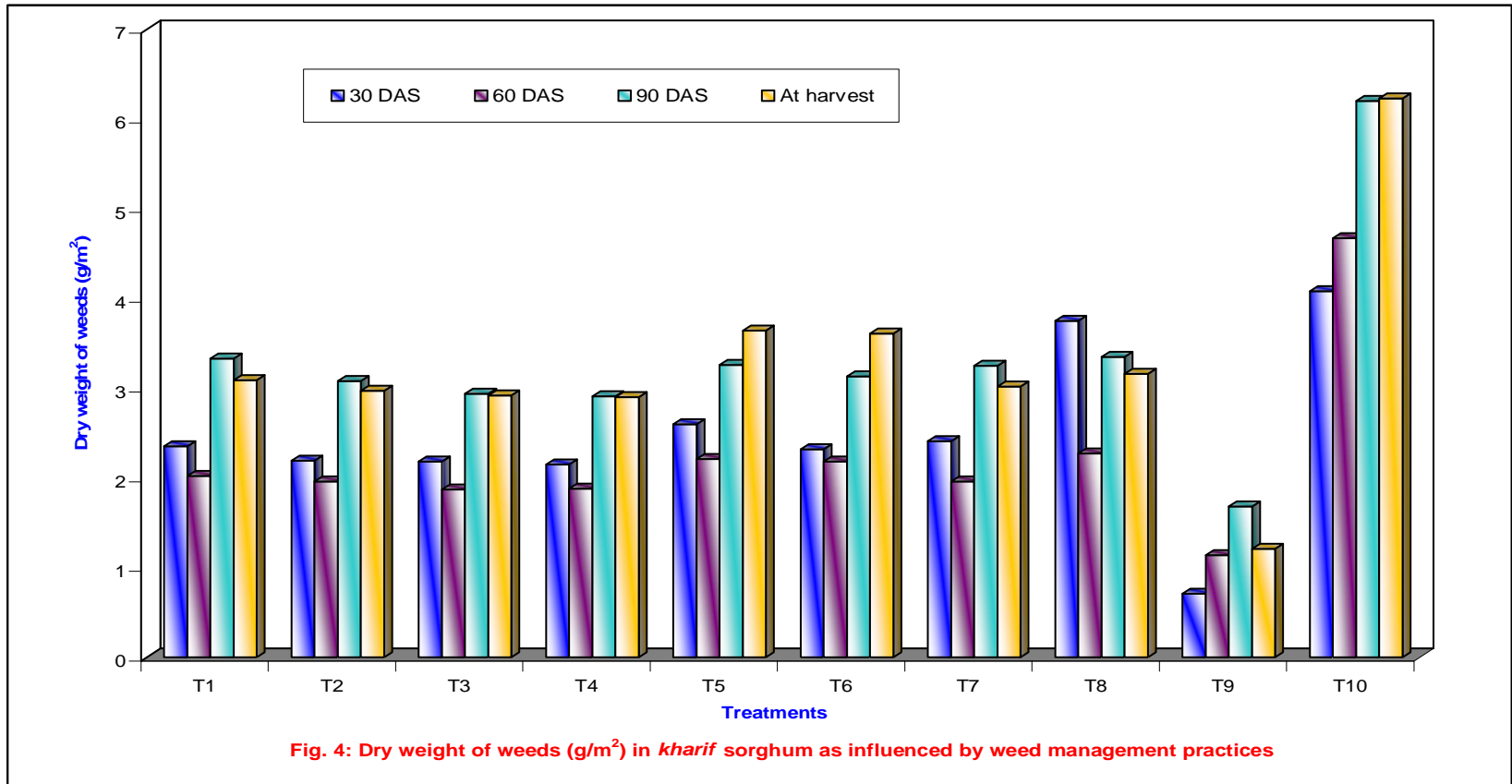


Fig. 4: Dry weight of weeds (g/m²) in kharif sorghum as influenced by weed management practices

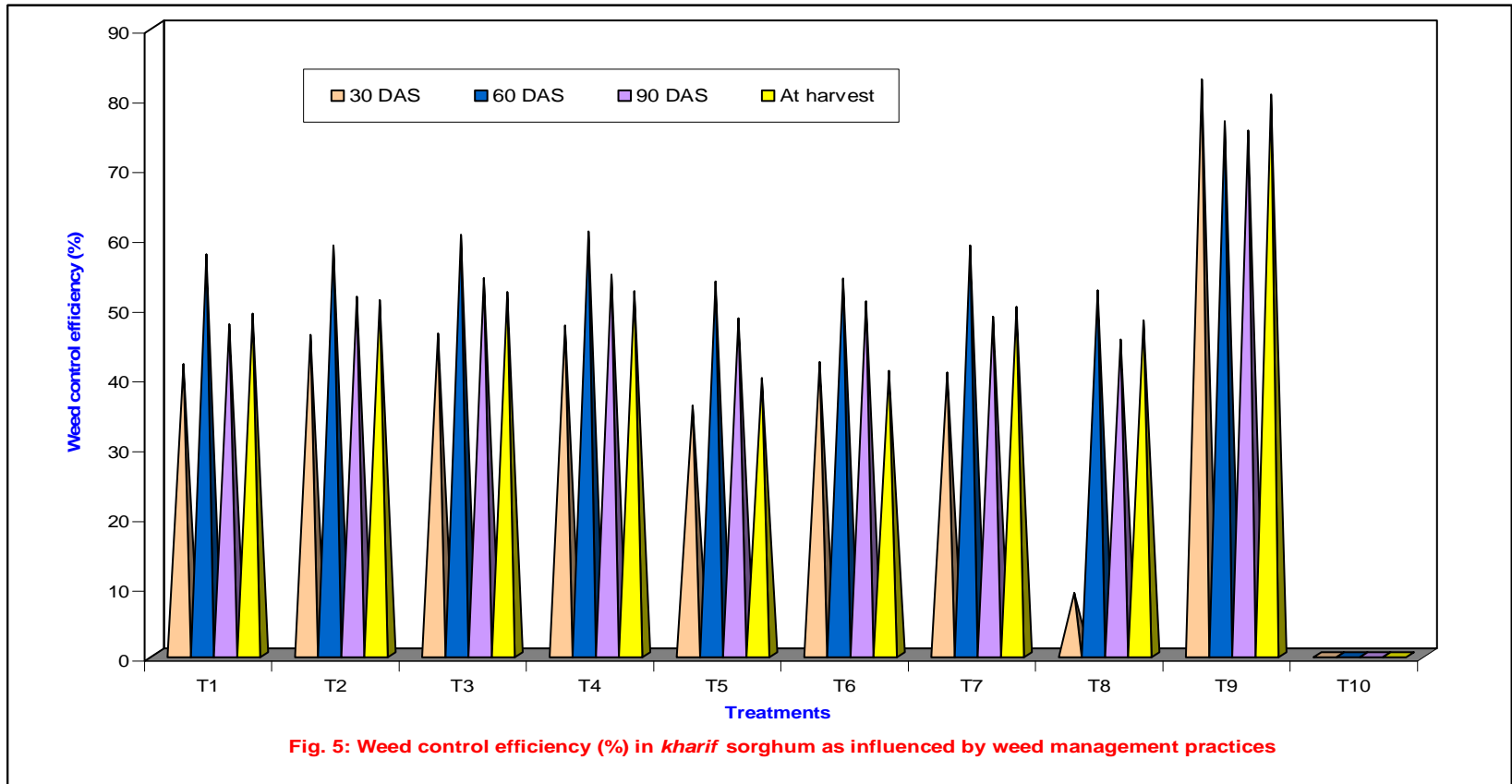


Fig. 5: Weed control efficiency (%) in kharif sorghum as influenced by weed management practices

5.6 Influence of different weed management practices on crop growth and yield

The differences in various yield components of sorghum, which led to the significant yield differences due to weed management practices could be traced back to differences in growth components.

Yield is the net result of various interactions viz., soil characters, weather parameters, crop-weed competition, leaf area and various metabolic and biochemical interactions taking place during crop growth. Sorghum grain yield is also influenced by dry matter accumulation in different parts especially in reproductive parts and yield components which is the product of interactions of above characters.

Yield and yield components of sorghum varied significantly among various weed control treatments (Table 21). The higher grain yield of sorghum (45.52 q ha^{-1}) was obtained with weed free check (Fig. 8). It was mainly due to minimum crop-weed competition throughout the crop growth period, thus enabling the crop for maximum utilization of nutrients, moisture, light and space which had influence on growth and yield components. The lower grain yield (31.62 q ha^{-1}) was noticed in weedy check (T_{10}) due to greater removal of nutrients and moisture by weeds and severe crop weed competition resulting in poor source and sink development with poor yield components and higher weed index (30.52%). These results are in conformity with the findings of Rout and Satapathy (1996), Sinha *et al.* (2005) and Kolage *et al.* (2004).

Significantly higher grain yield (44.24 q/ha) was obtained with atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2,4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_4) (Plate 6) when compared with weedy check. However, atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ (Plate 8) (41.58 q/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb atrazine @ $0.75 \text{ kg a.i. ha}^{-1}$ (Plate 9) (42.12 q/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2,4-D @ $0.5 \text{ kg a.i. ha}^{-1}$ (Plate 7) (42.27 q/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ + 1HW+2 IC (T_7) (43.30 q/ha) and farmer practice (T_8) (41.58 q/ha) were on par with T_4 . The per cent increase in grain yield over weedy check T_1 , T_2 , T_3 , T_4 , T_7 , and T_8 was to the extent of 31.49, 33.20, 39.91, 33.68, 36.93, and 31.49 per cent, respectively over weedy check. Various research workers have also reported effective control of weeds when herbicides were used Kachapur *et al.* (1973), Mohamed Ali and Sudhakara Roa, 1987, Satao and Nalamwar (1992), Satao *et al.* (1995), Wanjari *et al.* (1996), Saini and Angiras (1998), Sharma *et al.* (2000), Porwal, (2000), Girma and Chinawong (2005), Enrique *et al.* (2005), Anon. (2011-12), Shantveerayya and Agasimani (2012) and Singh *et al.* (1994). The higher grain yield in these treatments could be attributed to improved yield components such as higher grain weight per ear and 1000 grain weight (Table 21). The improvement in yield components was in turn due to improved growth attributes such as higher total dry matter production and leaf area index (Tables 20 and 16). Thus, the improvement in growth and yield components was as a consequence of lower crop-weed competition, which shifted the balance in favour of crop in the utilization of nutrients, moisture, light and space. These results are in conformity with the findings of Saini and Angiras (1998), Sreenivas and Satyanarayana (1994) and Kamble *et al.* (2005). Among the weed management practices, the lower grain yield of sorghum (34.11 q ha^{-1}) was obtained in pre-emergence application of atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ (PRE) fb post-emergence application of metsulfuron methyl @ 6 g a.i. ha^{-1} at 25 DAS (Plate 11) and 37.48 q ha^{-1} was obtained in atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} at 25 DAS (Table 21 and Plate 10). This was mainly due to phyto toxic affect of the herbicide on crop which was evidenced by lower values of growth and yield components. These results are in conformity with the findings of David *et al.* (2004).

Weed free-check also recorded the higher stover yield (10.46 t ha^{-1}) (Table 21) which was on par with atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ (T_1) (9.45 t/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb atrazine @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_2) (9.83 t/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2,4-D @ $0.5 \text{ kg a.i. ha}^{-1}$ (T_3) (9.83 t/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb 2,4-D @ $0.75 \text{ kg a.i. ha}^{-1}$ (T_4) (9.83 t/ha), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ + 1HW+2 IC (T_7) (9.32 t/ha) and farmers practice (T_8) (9.45 t/ha). The lower stover yield was recorded in atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 4 g a.i. ha^{-1} (7.88 t/ha) (T_5), atrazine @ $0.5 \text{ kg a.i. ha}^{-1}$ fb metsulfuron methyl @ 6 g a.i. ha^{-1} (6.95 t/ha) (Plate 12). This was mainly attributed to reduced total dry matter production in plants. Similar results were reported by Kannur (2008).



Plate 6: Pre-emergence application of atrazine @ 0.5 kg a.i ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ + 1IC at 60 DAS (T₄)



Plate 7: Pre-emergence application of atrazine @ 0.5 kg a.i ha⁻¹ fb post-emergence application of 2, 4-D @ 0.5 kg a.i. ha⁻¹ + 1IC at 60 DAS (T₃)



Plate 8: Pre-emergence application of atrazine @ 0.5 kg a.i ha⁻¹ fb post-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ + 1IC at 60 DAS (T₁)



Plate 9: Pre-emergence application of atrazine @ 0.5 kg a.i ha⁻¹ fb post-emergence application of atrazine @ 0.75 kg a.i. ha⁻¹ + 1IC at 60 DAS (T₂)

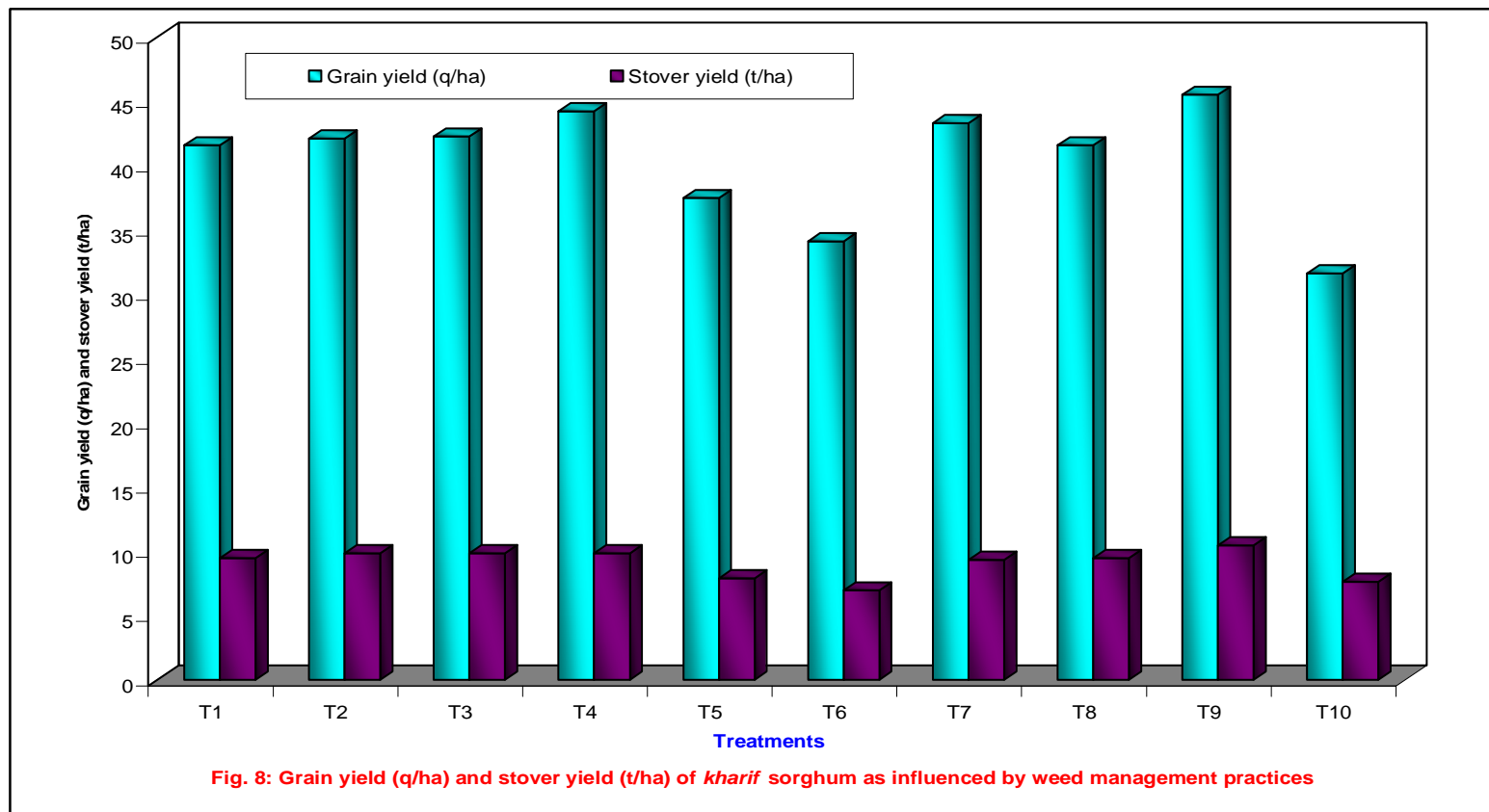


Fig. 8: Grain yield (q/ha) and stover yield (t/ha) of kharif sorghum as influenced by weed management practices



Plate 10: Phytotoxic effect of metsulfuron methyl @ 4 g a.i. ha⁻¹ (POST) on crop growth (T₅) at 60 DAS



Plate 11: Phytotoxic effect of metsulfuron methyl @ 6 g a.i. ha⁻¹ (POST) on crop growth (T₆) at 60 DAS

LEGEND

- T₁: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Atrazine @ 0.5 kg a.i. ha⁻¹(POST) at 25 DAS fb IC at 35 DAS.
- T₂: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Atrazine @ 0.75 kg a.i. ha⁻¹(POST) at 25 DAS fb IC at 35 DAS.
- T₃: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.5 kg a.i. ha⁻¹(POST) at 25 DAS fb IC at 35 DAS.
- T₄: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.75 kg a.i. ha⁻¹(POST) at 25 DAS fb IC at 35 DAS.
- T₅: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 4 g a.i. ha⁻¹(POST) at 25 DAS fb IC at 35 DAS.
- T₆: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha⁻¹(POST) at 25 DAS fb IC at 35 DAS.
- T₇: Atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) + 1HW+2 IC (Check-RPP)
- T₈: Farmers practice (1 HW fb 2 IC)
- T₉: Weed free check
- T₁₀: Weedy check



Plate 12: Phytotoxic effect of metsulfuron methyl @ 4 and 6 g a.i. ha⁻¹ (POST) on crop growth (T₆) at harvest



Plate 13: Effect of different weed management practices on ear head size

Difference in grain and stover yield among different weed management practices observed were mainly because of differences in yield and growth components. Among the yield components, grain weight per ear and 1000 grain weight were higher in weed free check (171.50 g and 34.81 g, respectively). On the other hand, weedy check recorded lower values of yield components. This lower yield and yield components might be due to reduced total dry matter production and leaf area index as consequence of inadequate translocation of metabolites to yield components due to severe competition for moisture, nutrients, light and space by weeds. Grain weight per ear and 1000 grain weight (Table 17) also varied with weed management practices. Atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹(T₄) recorded significantly higher grain weight per ear and 1000 grain weight (Plate 13). These results are in conformity with the findings of Kannur (2008) and Thakur and Sharma (1996). The correlation studies indicate that grain weight per ear (r=0.93), ear length (r=0.88), test weight 1000 seeds weight (r= 0.93) and stover yield (r=0.93) were significantly and positively correlated with grain yield (Table 25).

The significant improvement in grain yield in treatments such as T₄, T₃, T₂, T₁, T₇ and T₈ could also be attributed to increase in total dry matter production per plant at harvest (Table 21 and Fig. 7), which in turn was mainly due to increase in uptake of nutrients by the crop. The nutrient uptake (N, P and K) by the crop was significantly higher when compared with weedy check and other herbicide treatments (Fig. 9). The total dry matter production per plant at harvest was significantly higher in T₄ when compared with rest of the treatments. However T₃, T₂, T₁, T₇ and T₈ were on par with T₄. Significantly lower total dry matter production per plant was recorded in weedy check (T₁₀). The various research workers also reported that the herbicide treatments were effective in controlling weeds and improving the yield of sorghum significantly. (Rao *et al.*, 2007)

Among the various weed management practices atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher grain weight per ear compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) (24.15 g per ear), atrazine @ 0.5 kg a.i.ha⁻¹fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (24.60 g per ear) and was on par with rest of the treatments. Significant improvement in these parameters could be attributed to lower weed populations (Table 9), lesser dry weight of weeds (Table 12) and higher weed control efficiency (Table 13) which ultimately resulted in better crop growth leading to higher dry matter production per plant. This in turn might have resulted in better translocation of photosynthates to development of grain weight per ear. On the other hand the weedy check treatment recorded lower grain weight per ear due to severe competition by the weeds.

Contrary to the weedy check, significantly higher total dry matter production was observed in T₁, T₂, T₃, T₄, T₇, T₈ and T₉ (161.99, 163.61, 166.89, 171.72, 162.73, and 160.24 g plant⁻¹ respectively) at harvest due to better utilization of growth resources as a result of effective control of weeds. The various herbicides used were selective and were quite effective in controlling grasses and broad leaved weeds. This has ultimately reduced weed population and dry weight of weeds significantly.

Variations observed in total dry matter production in various weed management practices could be attributed to various growth components such as plant height (r=0.97), leaf area (r=0.98) and leaf area index (r=0.98) at 30 and 60 DAS.

The herbicide treatments such as T₁, T₂, T₃, T₄, T₇, T₈ and T₉ recorded significantly higher plant height (154.0, 156.0, 155.4, 154.2, 150.2, and 159.7 cm), leaf area (29.74, 31.09, 30.10, 31.84, 31.19, 28.33, and 32.51 dm² plant⁻¹), leaf area index (4.41, 4.61, 4.47, 4.72, 4.46, 4.40, and 4.82) between 30 to 60 DAS when compared to other herbicide treatments and weedy check. These parameters were significantly lowest in weedy check. Plant height (Table 14) differed significantly at all the growth stages of crop. Weed free check recorded significantly higher plant height at all the crop growth stages. Among herbicidal treatments, at 60 DAS, atrazine @ 0.5 kg a.i.ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher plant height (Kannur, 2008) which was on par with weed free check (T₉) in 60,90 DAS and at harvest. atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) or metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) found lower plant height. This is due to the phytotoxic nature of Metsulfuron methyl. This result is in conformity with that of David *et al.* (2004). Among the weed management practices, lower leaf area index was recorded in weedy check at all the crop growth stages.

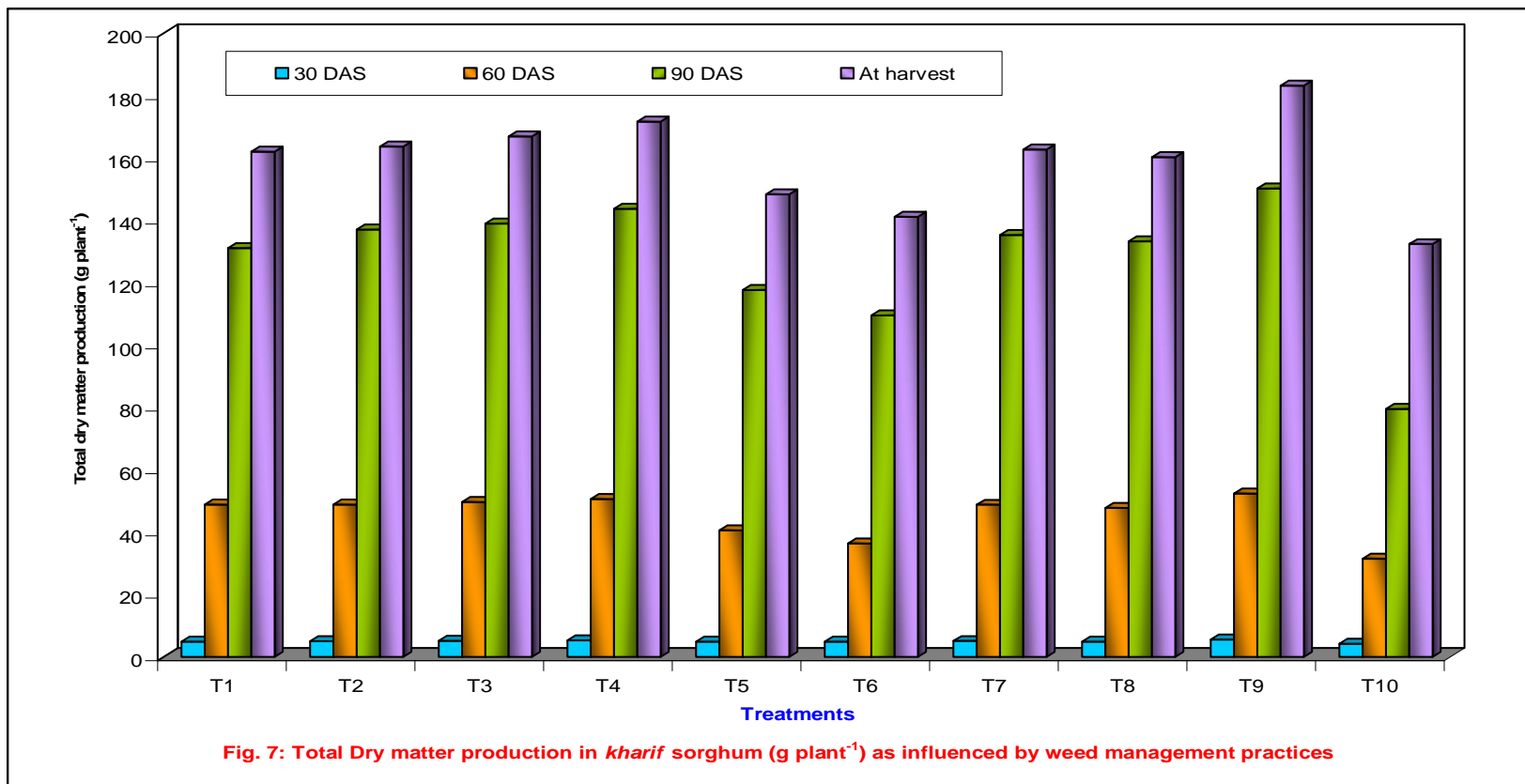


Fig. 7: Total Dry matter production in kharif sorghum (g plant⁻¹) as influenced by weed management practices

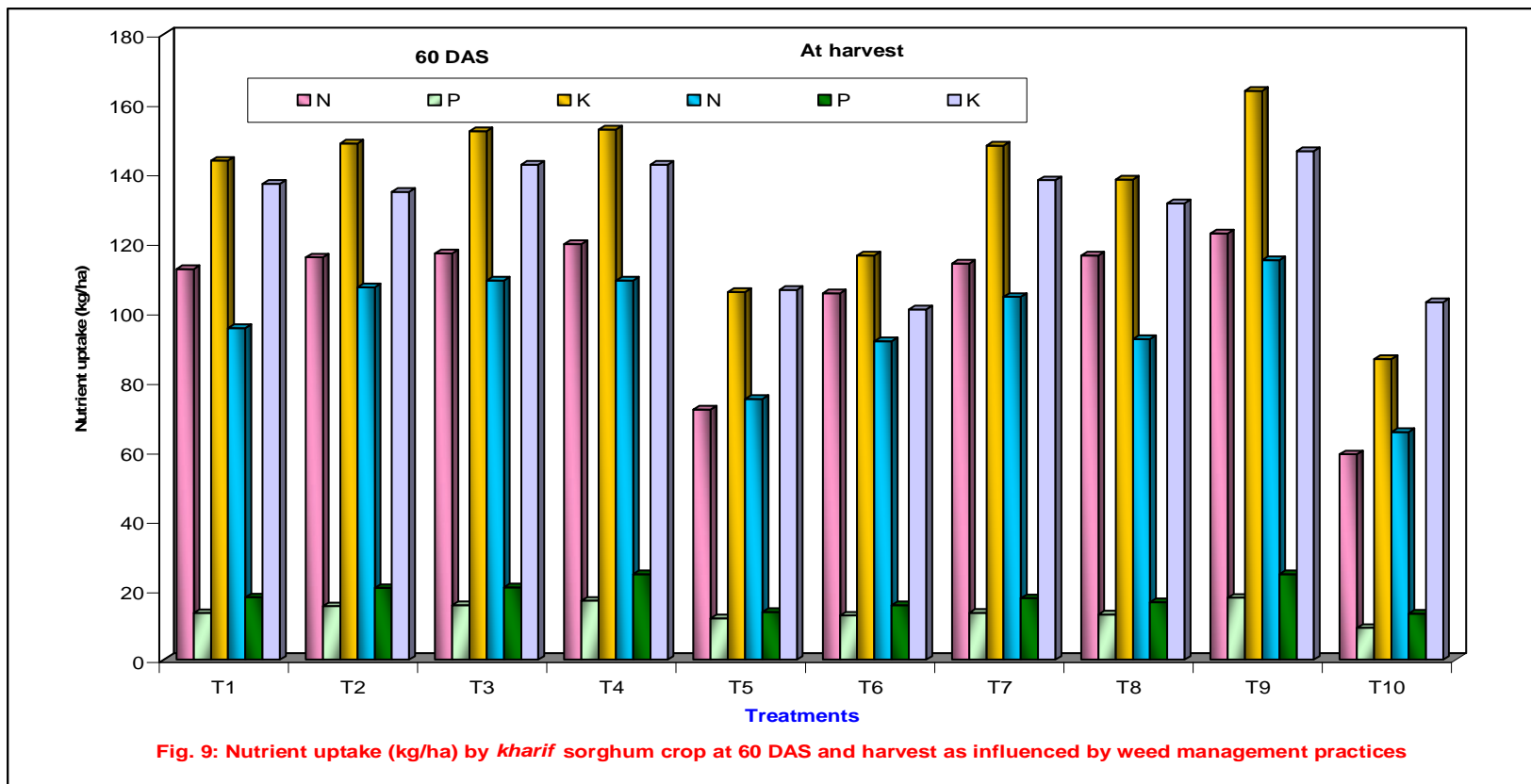


Fig. 9: Nutrient uptake (kg/ha) by kharif sorghum crop at 60 DAS and harvest as influenced by weed management practices

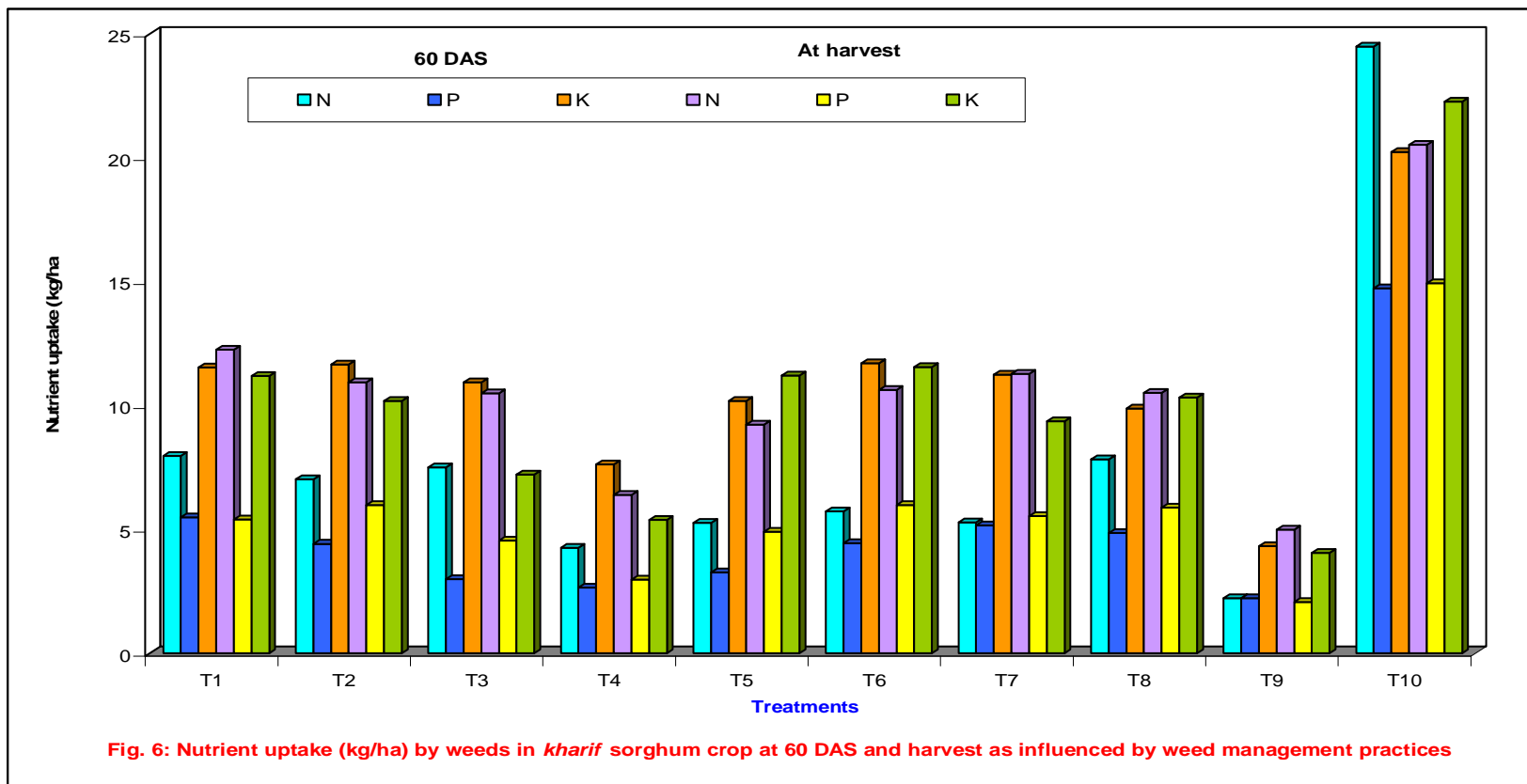


Fig. 6: Nutrient uptake (kg/ha) by weeds in kharif sorghum crop at 60 DAS and harvest as influenced by weed management practices

This might be due to severe competition of weeds for growth resources, which made the crop plant inefficient to utilize the resources consequently the growth was affected. The higher leaf area index was noticed in pre-emergence application atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) which was on par with weed free check in 60, 90 DAS and at harvest This could be attributed to better control of weeds in early and later growth stages of crop which provided the crop plants optimum environment to utilize growth resources efficiently resulting in better growth of crop.

Significant improvement in grain yield in treatments such as T₁, T₂, T₃, T₄, T₇, and T₈ could also be attributed to increase nutrient uptake by the crop at 60 DAS and harvest. The correlation coefficient between yield and nutrient uptake by the crop was significant and positively correlated (r=0.83 to 0.95). The weedy check treatment recorded significantly lower uptake of nutrients by crop at 60 DAS and harvest. On the contrary the nutrients removed by the weeds were higher in weedy check (Fig. 6). The correlation coefficient between grain yield of sorghum was significantly and negatively correlated with nutrient uptake by the weeds.

5.7 Economics of weed control treatments

Gross returns were significantly higher in atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (` 50,139.33 ha⁻¹) compared to atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹(T₅), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹(T₆) and was on par with rest of the treatments. The higher gross returns obtained in above treatments are mainly due to higher grain yield, stover yield and weed control efficiency.

With regards to net returns, application of atrazine @ 0.5 kg a.i. ha⁻¹ fb Atrazine @ 0.5 kg a.i. ha⁻¹ (T₁)(` 26,771 ha⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb atrazine @ 0.75 kg a.i. ha⁻¹ (T₂) (` 27,528 ha⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (T₃) (` 27,401 ha⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (` 29,529 ha⁻¹), atrazine @ 0.5 kg a.i. ha⁻¹ + 1HW+2 IC (T₇) (` 26,910 ha⁻¹) and farmer practice (T₈) (` 26,311 ha⁻¹) realised higher net returns and these treatments were on par with each other and significantly superior to other weed control treatments (Fig. 10). The higher net returns in these treatments could be attributed to higher grain yield, stover yield and lower cost of cultivation. The net returns in these treatments were significantly higher when compared to weedy check (T₁₀). Lesser net return in weedy check was mainly due to lower grain and stover yield. Sreenivas and Satyanarayana (1994), Pandey *et al.* (2002) Kamble *et al.* (2005), Rao *et al.* (2007) also reported the similar findings.

Benefit cost ratio was significantly higher with Atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (2.43) when compared with rest of the treatments (Fig. 10). This was mainly due to higher economic yield, net returns and lower cost of cultivation. However, treatments such as T₁ (2.29), T₂ (2.32), T₃ (2.33), T₇ (2.24), T₄ (2.43) and T₈ (2.24) recorded B: C ratio which was on par with T₄. The lower B: C ratio was recorded with atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 4 g a.i. ha⁻¹(T₅) (2.05), atrazine @ 0.5 kg a.i. ha⁻¹ fb metsulfuron methyl @ 6 g a.i. ha⁻¹(T₆) (1.93) followed by weedy check (T₁₀) (1.97). Though there were higher yield and gross income in weed free-check in comparison to atrazine @ 0.5 kg a.i. ha⁻¹ fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (2.43) the lesser B: C ratio in above treatments is mainly due to lower gross return and higher cost of cultivation. As such, hand weeding, though an effective operation, it is time consuming and labour intensive, impractical to perform under odd soil conditions and at early vegetative stages. Large amount of labour is required for hand weeding makes it's uneconomical especially where labour is expensive. The results are in conformity with the findings of Krishnamurthy and Krishnamurthy (1996).

5.8 Practical utility

The present investigation has brought out the following results of practical significance.

1. Pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ followed by post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded higher grain yield (44.24 q/ha), net income (` 29,529/ha), B: C ratio (2.43) and weed control efficiency.
2. Pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ followed by post-emergence application of atrazine @ 0.75 kg a.i. ha⁻¹ can also be used as an alternative herbicides which recorded on par grain yield, net return, B: C ratio and weed control efficiency.

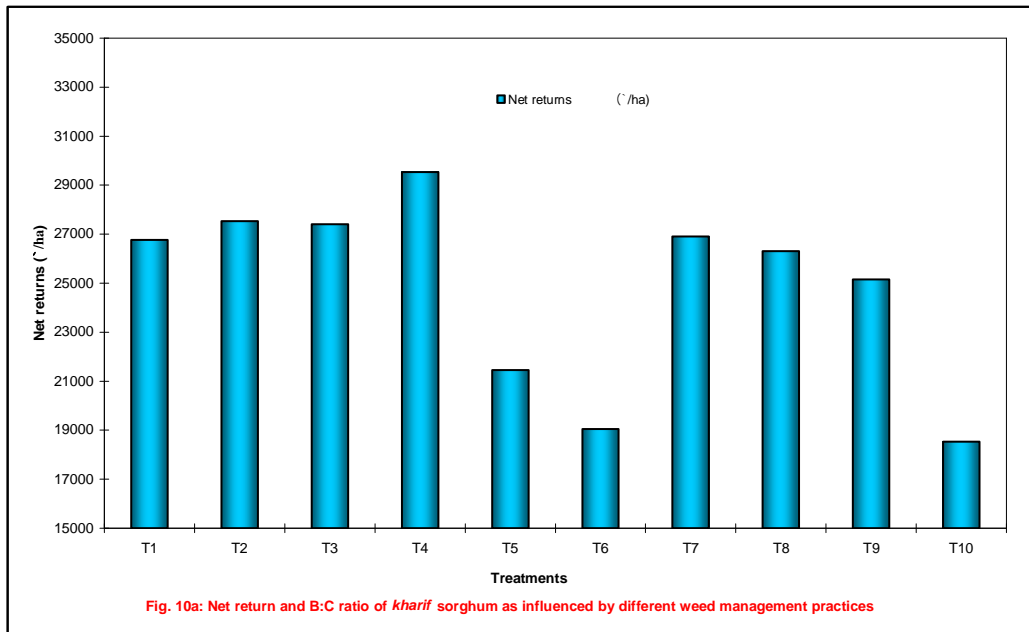


Fig. 10a: Net return and B:C ratio of kharif sorghum as influenced by different weed management practices

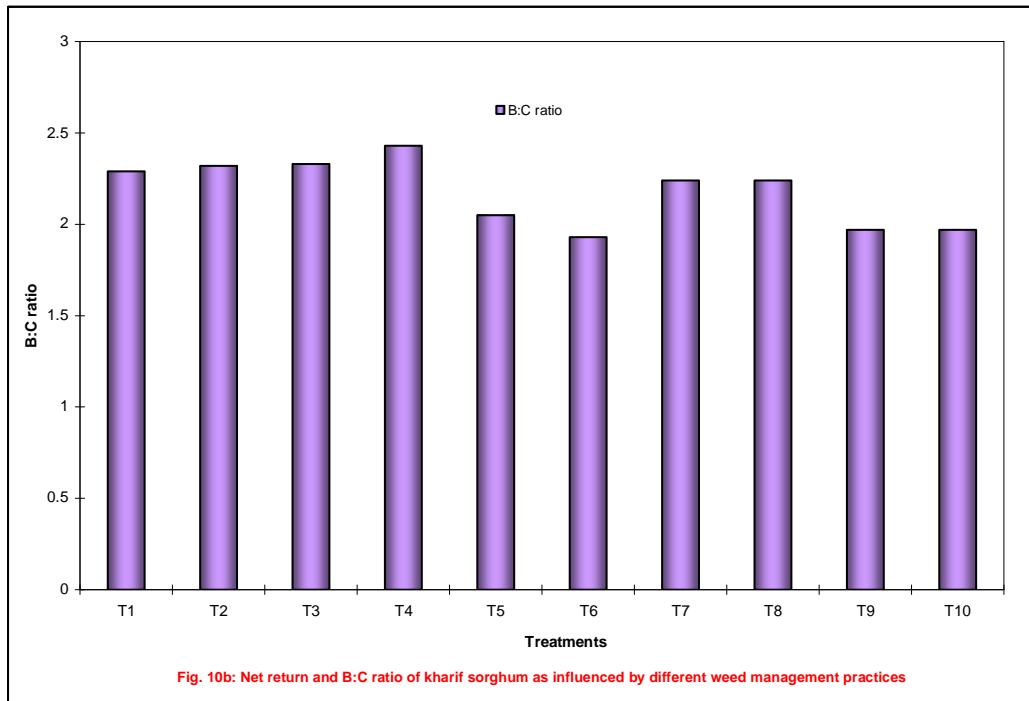


Fig. 10b: Net return and B:C ratio of kharif sorghum as influenced by different weed management practices

5.9 Future line of work

1. Studies are required on the effectiveness and bioefficacy of new generation herbicides and herbicides mixtures in sorghum.
2. Studies on residual effect of herbicides on crop grown in sequence, soil micro flora and fauna and also on the environment in long-run needs to be initiated.
3. Evaluation of broad-spectrum post-emergence herbicides on weed control is needed.

6. SUMMARY AND CONCLUSIONS

A field experiment was undertaken during *kharif* 2011 to study the Integrated weed management in *kharif* sorghum (*Sorghum bicolor* (L.) Moench) at Sorghum Research Scheme, Main Agricultural Research Station, Dharwad under rainfed condition. The experiment comprised of ten treatments laid-out in a randomized block design with three replications. Treatments consisted of pre-emergence herbicide (atrazine @ 0.5 kg a.i.ha⁻¹), post emergence herbicides (atrazine @ 0.5 kg a.i.ha⁻¹ (T₁), atrazine @ 0.75 kg a.i.ha⁻¹ (T₂), 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃), 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄), Metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) and Metsulfuron methyl @ 6 g a.i. ha⁻¹(T₆)), atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) + 1HW+2 IC (T₇), farmers practice (T₈), one weed free check (T₉) and weedy check (T₁₀). Some of the salient findings of above investigations are summarized in this chapter.

Weed flora

The weed flora noticed in the experimental site comprises of grasses, sedges and broad leaved weeds (Table 4). The important grassy weeds observed are *Cynodon dactylon*, *Digitaria sanguinalis* and *Dinebra retroflexa*, *Echinochloa colona*. *Cyperus rotundus* was lone weed under sedge category. Among broad-leaved weeds, *Ageratum conyzoides* L., *Amaranthus viridis*, *Amaranthus spinosus*, *Commelina benghalensis*, *Cynotis cucullata*, *Phyllanthus niruri* L. and *Mollugo verticillata* L. are the dominant weeds.

Weed control rating

The pre emergence herbicides (T₁, T₂, T₃, T₄, T₅, T₆ and T₇) recorded good to excellent control of weeds at 7, 14 and 21 DAS. There was a good to excellent control of weeds at 7 days after spraying of atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2, 4-D @ 0.5 kg a.i. ha⁻¹ (POST), atrazine @ 0.5 kg a.i.ha⁻¹(PRE) fb 2, 4-D @ 0.75 kg a.i. ha⁻¹ (POST). While treatments namely, atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb atrazine @ 0.5 kg a.i. ha⁻¹ (POST), atrazine @ 0.5 kg a.i.ha⁻¹(PRE) fb atrazine @ 0.75 kg a.i. ha⁻¹ (POST), atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2,4-D @ 0.5 kg a.i. ha⁻¹ (POST), atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (POST), atrazine @ 0.5 kg a.i.ha⁻¹(PRE) fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (POST) recorded good control of weeds.

Crop toxicity rating

The crop toxicity rating observed at 7, 14 and after 21days after pre-emergent herbicides revealed that there was no injury on the crop growth and the crop growth was normal. However, the crop toxicity was observed at 7, 14 and after 21 days after spraying of post-emergent herbicides. The slight stunting in growth of crop injury or discoloration of leaves and stems was observed in plots sprayed with atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb metsulfuron methyl @ 4 g a.i. ha⁻¹ (POST). Similarly some crop stand loss, stunting or discoloration of leaves and stem was observed in atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (POST) sprayed plots. While there was no phytotoxic injury on crop in other plots.

Effect of integrated weed management practices on weeds

The total weed dry weight, weed control efficiency and weed population of grasses, sedges and broad leaved weeds differ significantly among various weed control treatments. Among various weed management practices, pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly lower total weed dry weight at 30 and 60 DAS. The treatments namely T₁, T₂, T₃, T₅, T₆ and T₇ were statistically on par with T₄ at 30, 60DAS and at harvest. Significantly higher total dry weight was recorded with weedy check (T₁₀). At 60 and 90 DAS, pre-emergent application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃) recorded significantly lower total weed population as compared to rest of the treatments. The treatments such as T₁, T₂, T₃, T₄ and T₇ were on a par with T₃ at both stages. Weedy check recorded significantly higher total weed population of grasses, sedges and broad leaved weeds at both the stages as compared to others.

Weed control efficiency computed at 30 and 60 DAS revealed that, weed control efficiency was significantly higher in pre-emergent application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄). The treatments such as T₃, T₁, T₂, T₅, T₆, and T₇ were on par with T₄. Weedy check recorded significantly lower weed control efficiency at all the growth stages as compared to others. Nutrient uptake computed at 60 DAS and harvest recorded significant differences among various weed control treatments. Significantly higher nutrient uptake was recorded in weedy check at both the stages. The treatments namely T₁, T₂, T₃, T₄, T₅, T₆ and T₇ recorded significantly lower nutrient uptake at 60 DAS and harvest.

Effect of integrated weed management practices on sorghum

Grain and stover yield were significantly higher with the application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄). The treatments such as T₁, T₂, T₃, T₇, and T₈ were on par with weed free check and T₄. Lower grain and stover yield were recorded with weedy check, T₅ and T₆. Grain weight per plant and test weight was significantly higher with the pre-emergence application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄). The treatments such as T₁, T₂, T₃, T₇, and T₈ were on a par with weed free check and T₄. While weedy check, T₅ and T₆ recorded lower grain weight per plant and test weight. Weed index was significantly lower with atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄). The treatments such as T₁, T₂, T₃, T₇, and T₈ were on par with weed free check and T₄. While higher Weed index was recorded with weedy check and T₅ and T₆. Nutrient uptake at 60 DAS and harvest revealed that significantly higher nutrient uptake by crop was recorded in atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄). The treatments such as T₁, T₂, T₃, T₇, and T₈ were on par with T₄ at 60 DAS and harvest. However weedy check, T₅ and T₆ recorded significantly lower nutrient uptake by the crop.

The results on total dry matter production recorded at all the crop growth stages except 30 DAS revealed that application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher total dry matter production (TDMP) when compared to weedy check. However, T₁, T₂, T₃, T₄, T₇, and T₈ were on par with T₄. Significantly lower TDMP was recorded in weedy check, T₅ and T₆. Leaf area and leaf area index recorded at all the crop growth stages except 30 DAS revealed that application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergent application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher total dry matter production (TDMP) when compared to weedy check. However, T₁, T₂, T₃, T₄, T₇, and T₈ were on par with T₄. However, weedy check and T₅ and T₆ recorded significantly lower TDMP as compared to others. Plant height recorded at all the crop growth stages except 30 DAS indicated that application of atrazine @ 0.5 kg a.i. ha⁻¹ fb post-emergence application of 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄) recorded significantly higher plant height when compared to weedy check. However, T₁, T₂, T₃, T₄, T₇, and T₈ were on par with T₄. Significantly lower plant height was recorded in weedy check, T₅ and T₆.

Economics

Among various weed control treatments, gross returns were significantly higher in atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (` 50131) as compared to others. The treatments such as T₁, T₂, T₃, T₄, T₇, and T₈ were statistically on par with T₄. While lower gross returns was recorded in weedy check (` 37,602 ha⁻¹, atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb metsulfuron methyl @4 g a.i. ha⁻¹ (T₅) (41,864ha⁻¹ and atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb Metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) ` 39,476 ha⁻¹) as compared to rest of the treatments.

Economics of various weed control treatments indicated that higher net income was realized in atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (` 29,529 ha⁻¹) as compared to others. The treatments such as T₁, T₂, T₃, T₄, T₇, and T₈ were statistically on par with T₄. While lower net income was recorded in weedy check (` 318,537 ha⁻¹, atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb metsulfuron methyl @4 g a.i. ha⁻¹ (T₅) (` 21,451 ha⁻¹ and atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆) (` 19,049 ha⁻¹ as compared to others. Benefit: cost ratio (B: C ratio) was significantly higher in atrazine @ 0.5 kg a.i. ha⁻¹ (PRE) fb 2,4-D @ 0.75 kg a.i. ha⁻¹ (T₄) (2.43). However, the treatments such as T₁, T₂, T₃, T₄, T₇, and T₈ were statically on par with T₄. However, weedy check (1.97), recorded significantly lower benefit cost ratio as compared to others.

Based on the results obtained it may be concluded that,

1. Pre-emergence application of atrazine @ 0.5 kg a.i ha⁻¹ followed by 2,4-D @ 0.75 kg a.i ha⁻¹ recorded significantly lower weed density, weed dry weight and higher weed control efficiency followed by T₁, T₂, T₃, T₅ and T₆ compared to weedy check.
2. Grain yield, net return and B:C ratio were significantly with a pre-emergence application of atrazine @ 0.5 kg a.i ha⁻¹ followed by 2,4-D @ 0.75 kg a.i ha⁻¹ as compared to rest of the treatments.

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Appendix I: Prices of inputs and outputs

Sl. No.	Particulars	Price (₹)
I	Inputs	
1	Seeds	48/kg
2	FYM	500/t
3	Fertilizers	
a)	Urea	580/q
b)	Di Ammonium Phosphate	1920/q
c)	Muriate of Potash	530/q
4	Plant protection chemical	
a)	Furadon 3G	70/kg
b)	Phorate	70/kg
4	Herbicides rate	
a)	Atrazine	320/kg
b)	2, 4-D	250/kg
c)	Metsulfuron methyl	140/100g
5	Labour wages	
a)	Men	100
b)	Women	90
c)	Bullock pair with men	500
6	Tractor rates	
a)	Ploughing	3000/ha
b)	Harrowing	1250/ha
c)	Cultivator	1500/ha
d)	Sowing	1250/ha
II	Outputs	
a)	Sorghum grains	1000/q
b)	Stover	600/t

Appendix II: Details of cost of cultivation in different weed management practices (` ha⁻¹)

Sl. No.	Particulars	T ₁ Atrazine @ 0.5 kg a.i. ha ⁻¹ fb Atrazine @ 0.5 kg a.i. ha ⁻¹	T ₂ Atrazine @ 0.5 kg a.i. ha ⁻¹ fb Atrazine @ 0.75 kg a.i. ha ⁻¹	T ₃ : Atrazine @ 0.5 kg a.i. ha ⁻¹ fb 2,4-D @ 0.5 kg a.i. ha ⁻¹	T ₄ Atrazine @ 0.5 kg a.i. ha ⁻¹ fb 2,4-D @ 0.75 kg a.i. ha ⁻¹	T ₅ Atrazine @ 0.5 kg a.i. ha ⁻¹ fb Metsulfuron methyl @ 4 g a.i. ha ⁻¹	T ₆ Atrazine @ 0.5 kg a.i. ha ⁻¹ fb Metsulfuron methyl @ 6 g a.i. ha ⁻¹	T ₇ : Atrazine @0.5 kg a.i. ha ⁻¹ + 1HW+2 IC (Check- RPP)	T ₈ Farmers practice (1 HW fb 2 IC)	T ₉ Weed free check	T ₁₀ Weedy check
1	Land preparation										
a)	Deep ploughing	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
b)	Harrowing (bullock pair)	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
c)	Cultivator (twice)	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
2	Sowing by seed drill	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	Seed cost (sorghum)	360	360	360	360	360	360	360	360	360	360
3	Organic manure (10 t/ha)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
4	Plant protection chemicals	2395	2395	2395	2395	2395	2395	2395	2395	2395	2395
	Application charges	410	410	410	410	410	410	410	410	410	410
	Labour for FYM application	300	300	300	300	300	300	300	300	300	300
5	Fertilizer cost										
a)	Urea	887	887	887	887	887	887	887	887	887	887
b)	DAP	3130	3130	3130	3130	3130	3130	3130	3130	3130	3130
c)	MOP	223	223	223	223	223	223	223	223	223	223
	Application charges	360	360	360	360	360	360	360	360	360	360
6	Intercultivation	600	600	600	600	600	600	1200	1200	600	-
7	Hand weeding	-	-	-	-	-	-	900	900	6300	-
8	Herbicides cost	640	800	475	545	348	362	320	-	-	-
9	Application charges	400	400	400	400	400	400	200	-	-	-
10	Harvesting charges	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
11	Cost of cultivation	20705	20865	20540	20610	20413	20427	21685	21165	25965	19065

INTEGRATED WEED MANAGEMENT IN *KHARIF* SORGHUM (*Sorghum bicolor* (L.) Moench)

PRIYA H. R.

2012

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ABSTRACT

A field experiment was undertaken during *kharif* 2011 to study the Integrated weed management in *kharif* sorghum (*Sorghum bicolor* (L.) Moench) at Sorghum Research Scheme, Main Agricultural Research Station, Dharwad under rainfed condition. The experiment comprised of ten treatments laid out in randomized block design with three replications. Treatments consisted of pre emergence herbicide (Atrazine @ 0.5 kg a.i.ha⁻¹), post-emergence herbicides [Atrazine @ 0.5 kg a.i.ha⁻¹ (T₁), Atrazine @ 0.75 kg a.i.ha⁻¹ (T₂), 2, 4-D @ 0.5 kg a.i. ha⁻¹ (T₃), 2, 4-D @ 0.75 kg a.i. ha⁻¹ (T₄), Metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) and Metsulfuron methyl @ 6 g a.i. ha⁻¹(T₆)] with 1 IC at 35 DAS, Recommended package of practice (T₇), farmers practice (T₈), weed free check (T₉) and weedy check (T₁₀).

The weed control rating observed after pre and post-emergence herbicides revealed good to excellent control of weeds except T₁ and T₂. Atrazine gave satisfactory control at 7 DAS but at 14 and 21 DAS, it recorded good to excellent control of weeds. The crop toxicity rating observed after pre and post-emergence herbicides revealed that none of the herbicides had injury on the crop except metsulfuron methyl @ 4 g a.i. ha⁻¹ (T₅) and metsulfuron methyl @ 6 g a.i. ha⁻¹ (T₆), which showed slight discoloration of leaves and stem and also stunting at 7 and 14 days after post-emergence spray.

Pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb 2,4-D either @ 0.5 or 0.75 kg a.i ha⁻¹ significantly reduced weed density, weed dry weight and nutrient uptake by the weeds at 60, 90 DAS and at harvest. Weed control efficiency, total dry matter production and nutrient uptake by the crop were significantly higher in these treatments compared to rest of the treatments except weed free check. Pre-emergence application of atrazine @ 0.5 kg a.i.ha⁻¹ fb 2,4-D @ 0.75 kg a.i ha⁻¹ recorded significantly higher grain yield (44.25 q ha⁻¹), stover yield, net returns (₹ 29,529) and benefit: cost ratio (2.43) compared to T₅, T₆ and weedy check.