

**WEED DYNAMICS AND CROP PRODUCTIVITY AS INFLUENCED
BY PREPARATORY TILLAGE AND WEED MANAGEMENT
METHODS IN SUNFLOWER-MAIZE CROPPING SYSTEM**

Thesis submitted in part fulfillment of the requirements for the award of Degree of
MASTER OF SCIENCE (AGRICULTURE) IN AGRONOMY to the Tamil Nadu
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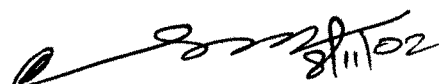
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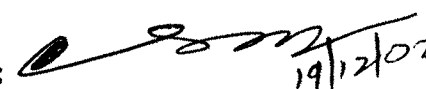
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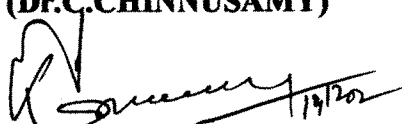
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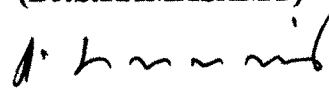

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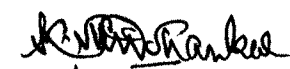
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(C. LEELA)

ACRONYMS AND ABBREVIATIONS

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N	Nitrogen
P	Phosphorus
K	Potassium
°C	Celsius
m	Metre
g	Gram
/ha	per hectare
m ²	Square metre
cm	Centimetre
CD	Critical difference
NS	Non significant
Max.	Maximum
Min.	Minimum
SEd	Standard error of deviation
DMP	Dry matter production
CGR	Crop growth rate
RGR	Relative growth rate
NAR	Net assimilation rate
LAI	Leaf area index
DAS	Days after sowing
1000/ha	Thousands per hectare
B:Cratio	Benefit cost ratio
Rs. /ha	Rupees per hectare
Kg/ha	Kilogram per hectare
g/g/day	gram per gram per day
g/m ² /day	gram per square metre per day
mg/dm ² /day ¹	Milligram per square centimetre per day

ABSTRACT

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WEED DYNAMICS AND CROP PRODUCTIVITY AS INFLUENCED BY PREPARATORY TILLAGE AND WEED MANAGEMENT METHODS IN SUNFLOWER-MAIZE CROPPING SYSTEM

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Field experiment was conducted during *kharif* and *rabi* seasons of 2001-2002 at Tamil Nadu Agricultural University, Coimbatore to study the weed population dynamics and crop productivity as influenced by preparatory tillage and weed management methods in sunflower-maize cropping system. The experiment was laid out in strip plot design with three replications. Main plot treatments consisted of five different preparatory tillage methods namely two deep tillages (disc or mould board ploughing followed by cultivator tillage twice), two shallow tillages (country plough or cultivator tillage twice) and a minimum tillage without any preparatory tillage for sunflower crop alone in sunflower-maize cropping system. Three weed management methods *viz.*, pre-emergence herbicide (pendimethalin 0.50 kg/ha + metolachlor 0.05 kg/ha for sunflower and atrazine 0.25 kg/ha for maize) application followed by hand weeding on 40 DAS, manual weeding twice or mechanical weeding twice with a rotary weeder on 20 and 40 DAS along with an unweeded check for both the crops consisted the sub plot treatments.

Observations were recorded on weed characters like weed flora, weed density and weed dry matter and crop parameters like plant height, dry matter production, leaf area along with physiological growth parameters and yield attributes. Grain yields of both the crops and stover yield of maize were weighed to assess the crop productivity. Nutrient

uptake by crops and removal by weeds as well as economic aspects like gross and net returns, benefit-cost ratio, per day return were also estimated to record the influence of preparatory tillage and weed management methods.

Cynodon dactylon, *Dactyloctenium aegyptium* among grasses, the only sedge *Cyperus rotundus* and broad-leaved weeds, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* were the predominant weeds. Shallow preparatory tillages reduced the grassy weeds, while broad-leaved weed population was reduced with deep tillage. Combination of herbicidal + manual weeding with deep tillages reduced the weed density to a greater extent.

Deep preparatory tillages improved the growth attributes, physiological parameters and yield attributes of both sunflower and maize. Pre-emergence application of herbicide mixture pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize performed better by increasing the growth attributes, physiological parameters and yield attributes of both the crops. Higher seed yield of sunflower, grain and stover yields of maize were obtained with deep preparatory tillage and integrated herbicide + manual weeding methods. Disc ploughing followed by cultivator tillage resulted in higher weed control efficiency with the least yield reduction. Hand weeding and mechanical weeding twice were comparable in recording lesser yield reduction against unweeded control. Herbicidal + manual weeding resulted in higher weed control efficiency. Higher nutrient uptake by crop plants and lower removal by weeds were recorded with disc ploughing followed by cultivator tillage and pre-emergence herbicide application followed by manual weeding.

Preparatory tillage with disc plough followed by cultivator tillage combined with application of pre-emergence herbicide followed by manual weeding resulted in higher gross and net returns, whereas higher returns per rupee invested and higher per day returns were obtained with minimum tillage combined with herbicide application followed by manual weeding in sunflower. In maize, higher gross and net returns with better returns per day and per rupee could be obtained with deep preparatory tillage for preceding sunflower combined with integrated herbicide + manual weeding for maize.

Disc ploughing followed by cultivator tillage among the preparatory tillage methods and herbicide followed by manual weeding in case of weed management methods resulted in higher maize grain equivalent yield of the system. Highest net returns and per day returns for the system were obtained with cultivator tillage combined with integrated management of herbicide + manual weeding, whereas higher income per rupee invested was obtained with minimum tillage combined with herbicidal + manual weeding.

From the results of the field experiment, it could be concluded that preparatory tillage with disc plough followed by cultivator tillage twice for preceding sunflower with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by one hand weeding on 40 DAS can keep the weed density and dry matter below the economic threshold level and increase the productivity and profitability of sunflower-maize cropping in the Western Zone of Tamil Nadu. Minimum tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by one hand weeding on 40 DAS could be adopted as suitable tillage and weed management methods to obtain higher economic returns per rupee invested on cost of cultivation with better per day returns in sunflower-maize cropping system.

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INTRODUCTION

CHAPTER I

INTRODUCTION

The world food grain production loss due to weeds was estimated to be 287 million tonnes accounting for 11.5% of the total food production. As per the estimate of 1992, when compared to losses of 26 and 20% caused by diseases and insects respectively in field crops, weed is an important pest causing 33% of total loss. The total annual losses caused by weeds are estimated to be Rs.1980 crores in India alone. In India, weed management takes 30-50% share of the total cost of cultivation (Bhan, 1997). It illustrates the importance of weed control in minimizing the yield losses and stepping up the crop productivity. Costs on weed control are the largest variable cost in most crop cultivation. Therefore, weed management is one of the primary elements of crop management systems to realize higher food production targets to meet the food demand of exploding population.

Sunflower is an important oil seed crop of India. Wide row spacing and slow initial growth of sunflower provide enough room for weeds to establish and to take advantage of slower initial growth of the crop. Uninhibited growth of weeds causes enormous loss of nutrients, which in turn reduces the yield of sunflower upto 64% (Legha et al., 1992). Maize is the third most important cereal grain crop after wheat and rice. As the crop is heavily fertilized and sparsely grown, severe weed infestation is experienced, resulting into a drastic reduction of grain yield. Yield losses due to weeds varied from 28 to 93% depending on the type of weed flora and their intensity, stage, nature and duration of crop-weed competition (Sharma and Thakur, 1998).

Cropping system influences the weed control as it results in weed population shifts due to various practices viz., land preparation, organic and fertilizer nutrient application and herbicidal application or other means of weed management. Farmers of Western and North Western zones of Tamil Nadu, have shifted from cotton based cropping systems to maize based cropping systems, as the cotton crop is being highly infested with pests and diseases and the net returns are drastically reduced. The farmers have shifted to maize

based cropping systems, which ensure higher returns owing to its maximum utilization by poultry industry and less cost of cultivation.

Tillage is the mechanical manipulation of surface soil to provide a favourable environment for the germination and proper development of seeds in addition to the suppression of native weeds. Tillage affects the vertical distribution of weed seeds within the soil profile. Further, tillage can affect weeds directly, as in the destruction of annual weeds during seeded preparation, or the effect may be more subtle, as in the shift from large seeded broad leaved weeds to small seeded weeds in reduced tillage systems.

Manual and mechanical methods of weed control are labour intensive, costly and time consuming and often needs to be repeated at different intervals. Besides, frequent rainfall during cropping season does not permit manual and mechanical methods at the appropriate time. Thus, to eliminate weed competition from the germination stage of the crop and to reduce the yield losses, chemical control has become inevitable. Optimum doses of pre-emergence herbicides could be applied properly to reduce the weed competition at critical period of weed interference without much disturbance to crop growth and soil health. Complete control of weeds is hard to achieve by using any single method of weed control. Continuous use of herbicides over a prolonged time leads to development of resistance in weeds making them difficult to control. However, if the various components of integrated weed management are blended in a systematic way, acceptable level of weed control can be achieved.

Research results on the effect of preparatory tillage on crop productivity and other related soil environment as well as the control efficiency of different weed management methods and their effect on crop growth and yields are available adequately. However, the information on the influence of preparatory tillage methods on weed population and their control and efficiency of different weed management methods on the productivity of crops in a system and their interactive effects on the cropping system productivity are seldom available. Hence, a field

experiment was programmed to develop information on weed population dynamics in sunflower-maize cropping system as influenced by preparatory tillage and weed management methods under irrigated conditions with the primary **objectives**:

- ❖ To study the weed population dynamics as influenced by preparatory tillage and weed management methods in sunflower-maize cropping system.
- ❖ To develop an efficient integrated weed management method for higher productivity of sunflower-maize cropping system.
- ❖ To identify the interaction effect of preparatory tillage and weed management methods on weed population dynamics, productivity and profitability of sunflower-maize cropping system.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Weeds constitute a major component among the bottlenecks for successful crop production. Weeds are generally hardy species and have a vigorous and deep root system and compete very efficiently with cultivated crops for the nutrients available in the soil and for the much needed moisture and sunlight. Tillage helps in controlling weeds by burying the weed seeds and emerged weed seedlings leaving a rough surface to hinder weed seed germination and expose underground parts of perennial weeds leading to desiccation. Specific weed management techniques like manual, mechanical and herbicidal methods are found to be effective in controlling different groups of weeds in cropped fields. Relevant literatures pertaining to the effect of preparatory tillage and weed management methods on weed control and crop productivity in sunflower and maize cropping are reviewed in this chapter.

2.1. WEED FLORA OF THE CROPPED FIELDS

2.1.1. Sunflower

Effective weed control strategies could be formulated only when the weed flora composition of the field is known very well. Sunflower being a slow growing broad-leaved crop at initial growth stages, the weed flora composition varies widely with soil types and cultivation methods. The dominant weeds associated with sunflower in clay loam soils of Coimbatore were *Trianthema portulacastrum* L., *Digera arvensis* Forsk., *Lagasca mollis* Cag., *Gynanadropsis pentaphylla* DC., and *Cyperus rotundus* L. (Raju and Sankaran, 1974). Whereas, in Southern zone of Tamil Nadu, pre-dominant weeds observed were *Cyperus rotundus*, *Cynodon dactylon* (L) Pers., *Panicum repens*, *Digera arvensis*, *Phyllanthus niruri* L., *Trianthema portulacastrum*, *Corchorus olitorius* and *Borreria hispida* (AICRP-WC, 1988b). In red sandy loam soils under irrigated conditions of Bangalore and Southern Karnataka, *Cynodon dactylon*, *Cyperus esculentus*, *Cyperus rotundus*, *Digitaria marginata* Link, *Eragrostis* spp., *Commelina benghalensis* L., *Leucas aspera* Link (Wild.), *Acanthospermum hispidum* DC, *Borreria hispida* K. Sch., *Trichodesma indicum* LR.Br and *Phyllanthus niruri*, were the major weeds (Gowda *et al.*, 1987; AICRP-WC 1984; 1988a). Girijesh and Patil

(1989) observed *Cynodon dactylon*, *Cyperus rotundus*, *Digitaria marginata*, *Echinochloa crusgalli* (L.) Beauv., *Ageratum conizoides* L., *Abutilon indicum* (L.), *Commelina benghalensis* and *Phyllanthus niruri* as dominant weeds in clay soils of Dharwad, North Karnataka. Whereas in clayloam soils of Coimbatore, Nalayini (1990) observed that weeds like *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Trianthema portulacastrum*, *Cyperus rotundus*, *Flavaria australasica* Hook. and *Amaranthus viridis* L were the dominant ones in cropped fields. In Central Maharashtra, major weeds observed were *Brachiaria eruciformis*, *Convolvulus arvensis*, *Argemone mexicana*, *Cyperus rotundus* and *Commelina benghalensis* L. Whereas, in Central Vidharbha zone, the weeds were *Celosia argentea*, *Brassica cruciformis*, *Commelina benghalensis*, *Digitaria retroflexus* and *Cyperus rotundus* (AICR-WC, 1991). However, *Brassica cruciformis*, *Parthenium hysterophorus* L., *Cynodon dactylon*, *Euphorbia dracunculoides*, *Euphorbia hirta* and *Sonchus arvensis* L. were noticed as major weeds in Western Maharashtra regions.

2.1.2. Maize

Maize being a narrow leaved fast growing cereal even from its early part of the growing period, weed flora varies with soil ecosystem and type of cultivation. The major weed flora of maize field in loamy soils of Himachal Pradesh were *Cynodon dactylon*, *Legasca mollis* and *Cyperus* spp and constituted 27.0, 23.3 and 15.4% of the total weed density, respectively (Chandrasagar, 1983). Whereas, in Hisar, with slightly alkaline sandy loam and medium fertile soils, the dominant weed flora consisted of *Echinochloa colonum*, *Trianthema portulacastrum*, *Cyperus rotundus*, *Digera arvensis*, *phyllanthus niruri* and *Amaranthus viridis* in maize fields (Yadav *et al.*, 1985). However, Angiras and Singh (1988) reported that *Cyperus esculentus*, *Echinochloa* spp, *Polygonum alatum*, *Digitaria sanguinalis* were the predominant weeds with maize in silty clay loam soils of Himachal Pradesh. They also observed that other weeds such as *Eleusine indica*, *Seteria glauca*, *Cynodon dactylon*, *Euphorbia heterophylla* and *Sorghum halopense* were at low in density in maize fields. Whereas, Nayital *et al.* (1989) observed that *Cyperus rotundus*, *Eleusine indica*, *Echinochloa colonum*, *Digitaria sanguinalis* and *Dactyloctenium aegyptium* were predominating weeds at silking stage of maize in sandy loam soils of Bajaura (Kullu) region of

Himachal Pradesh during rainy season. Predominant weeds at Arlington were Common lambsquarters (*Chenopodium album* L.) and red root pigweed (*Amaranthus retroflexus* L.) in the non herbicide plots and velvet leaf (*Abutilon theophrasti* Medic.) in the herbicide treated plots of maize field, whereas at Walworth Country, giant foxtail (*Setaria faberi* Herlm.) dominated among the maize field weeds (Mulder and Doll, 1993). In the maize fields of Simcoe (Ontario), where the soil was a Berrien sandy loam (Sandy, mixed, Calcareous, mesic typic Hapludalf), Sullivan and Bouw (1993) reported that the predominant broad leaf weeds present were lady's thumb (*Polygonum persicaria* L.), Sheperd's purse (*Capsella bursapastaris* L.), common purslane (*Portulaca oleracea* L.) and red root pigweed (*Amaranthus retroflexus* L.). Similarly, Sher Singh and Rajput (1995) reported that the most outstanding weed flora composition in the experimental fields at Faizabad included *Cyperus rotundus*, *Launea asplenifolia*, *Chenopodium album*, *Anagallis arvensis*, *Phyllanthus niruri*, *Melilotus indica*, *Ganaphalium pulvinatum*, *Polygonum plebejum*, *Trianthema monogyna* and *Euphorbia dracunculoids* with maize fields in sandy loam soils.

2.2. CROP-WEED COMPETITION

The degree of crop-weed competition is determined by the weed species and their density, duration of infestation, associated crops in the field, growth habit of crop plants and environmental conditions. Weeds that grow with crops deplete considerable amount of costly fertilizer nutrients, limited moisture, light and space, thereby leading to poor growth and development and lower yields of crops.

2.2.1 Critical period of crop-weed competition

The critical period of crop-weed competition is the period of crop growth wherein the actual competition between crop plants and weeds is maximum and that leads to drastic yield reduction if weeds are left uncontrolled during that crop growth period. The critical crop-weed competition period varies with the crop growth and architecture in addition to its management methods.

2.2.1.1. Sunflower

Sunflower would produce maximum seed yields, if fields were kept weed free for four to six weeks after sowing (Johnson, 1971). Singh and Singh (1978) observed that crop-weed competition in sunflower was for a period of first 60 days and keeping the fields weed free longer than that did not cause any beneficial effect. Keeping the weed free condition for first 45 days after sowing was sufficient enough to produce highest seed yield of sunflower (Anon, 1979). Farizo *et al.* (1980) observed that the critical period for weed competition in sunflower extended from the formation of ninth leaf to the beginning of flowering. A critical period of weed competition during which sunflower crop should be kept weed free was reported to be the first 30 DAS (Gimenoz and Rios, 1986) 45 DAS (Catullo *et al.*, 1983) and 60 DAS (Gowda *et al.*, 1987). Altieri and Liebmann (1988) and Styrbjorn (1990) reported that the most competition between crops and weeds usually occurs in the first one-third of the crop life cycle period.

2.2.1.2. Maize

Maximum crop-weed competition in maize was during the period of two to six weeks after sowing (Sandhu and Gill, 1973). According to Parker (1983) weeds posed serious threat to maize between 20 and 60 days after sowing for yields. A weed free condition till knee-high stage was found to be beneficial for higher yield in maize (Kharwara *et al.*, 1984). Similarly, Bonilla (1984) observed more severe weed competition up to 30 to 40 days after crop emergence. Under mid-hill condition of North Western Himalayas the first 40 days after emergence was found to be critical for weed competition in maize (Kampta Prasad and Mani, 1986). Sharma and Zelaya (1986) also reported that the critical period of competition between crop and weed was between 30 and 45 days after sowing. According to Ammon (1988) the critical period for maize last approximately from the 2-3 leaves stage until the plants were about 30-40 cm high, which doesn't represent more than one month. Studies conducted at Bajaura (Kullu) to evaluate the critical period of weed removal and the effect of period of weed removal and the effect of weed competition on maize showed that 20 and 60 days after sowing was observed to be the critical period (Nayital *et al.*, 1989). Shad *et al.* (1993) reported that the critical period of crop weed competition in maize was

found to be in between three and five weeks after sowing. However, Gosheh *et al.* (1996) observed that the critical period of crop-weed competition was between three to six weeks after corn emergence, where the field was severely infested with Johnson grass.

2.2.2. Competition for nutrients and moisture

Competition between plants is maximum when available resources for crop growth become limiting. In general competition between crops and weeds was more severe when the competing plants have similar vegetative habits and demands upon most important resources like nutrients and moisture.

2.2.2.1. Sunflower

Sunflower being an oil seed crop, requires more amount of phosphorous and potassium for its higher productivity. As weeds compete for nutrients in many folds at its early growth stage, the competition for major nutrients by weeds will reflect on the nutrient uptake and productivity of sunflower. Poonguzhalan (1992) reported that the nutrient removal by weeds in sunflower was minimum. Similarly, Legha *et al.* (1992) and Jat and Giri (2000) observed that uninhibited growth of weeds caused enormous loss of nutrients which in turn reduced the seed yield of sunflower.

2.2.2.2. Maize

Maize being a coarse grain cereal requires heavy amounts of fertilizer nutrients and the unchecked weed growth during the critical periods of its growth make the competition more acute. Hosmani (1976) opined that weeds were capable of absorbing just as much as (or) even higher amounts of moisture than crop plants, and also found that more than 66% moisture loss was effected by weeds in maize. Generally, weeds have higher content of nutrients than crop plants and they grew faster and absorb nutrients and moisture earlier and also reduced the light availability and space to crop plants (Rao, 1983). According to Okumura *et al.* (1986), under weedy condition, about 80 per cent of the available nitrogen was used up by the weeds until the maize crop was approximately 50 cm high. In Poland, it was reported that, presence of *Amaranthus retroflexus* (20/m²) in maize field, removed greatest amount of NPK and

reduced nutrient uptake of maize by 38% (Rola and Rola, 1992). According to Santos *et al.* (1993) under silty loam soil condition, weeds had accumulated 98 kg N/ ha in their tissues within 6 weeks after sowing of maize. In general weeds under maize crop removed 52.3, 9.6 and 38.9 kg NPK/ha respectively (Sreenivas and Satyanarayan, 1996). Balasubramanian and Veerabadran (1998) reported that in general, reduction in nutrient removal by weeds through suitable weed management practices enhanced the nutrient uptake, dry matter production and grain yield of crops.

2.2.3. Effect of competition on growth and yield components.

Competition between crop and weed is most severe when the competing plants have similar vegetative habits and demand upon same resource. The growth and yield attributes of crop plants associated with profuse growth of uncontrolled weeds would be reduced drastically reflecting on the yield of crops.

2.2.3.1. Sunflower

Sunflower growth parameters such as plant height, number of leaves and leaf area index were reduced due to the presence of weeds throughout the crop growth period (Johnson, 1971). Similarly, Raju and Sankaran (1974) reported that plant height, number of leaves and leaf are index were decreased due to weed infestation throughout the growth period of sunflower. They further observed that the average height of sunflower plants was not influenced by the weed competition. Whereas, Gosh *et al.* (1979) reported that there was steady increase in the vigour of sunflower plants with decrease in weed dry weight.

2.2.3.2. Maize

There was a significant reduction in height of maize plants with unchecked weed growth throughout the crop growth period (Chakor and Awasthi, 1983). Young *et al.* (1984) reported that quack grass (*Agropyron repens* Beauv.) interference in corn reduced the plant height, leaf area and photosynthetic productivity. Uncontrolled weeds decreased cob length and grain number per cob by 20 and 30% respectively and cob and stalk diameter by 10 and 20%, respectively (Beck, 1985). Similarly, Balayan and Bhan (1987) registered significant reduction in yield attributes, viz., cobs per

plant, grains per cob, 100 grains weight due to the presence of dominant weeds like *Trianthema portulacastrum* and *Echinochloa colonum* in maize fields.

2.2.4. Effect of weed competition on yield

In situations ideal or otherwise for crop and weed growth, weeds always thrive well. Increase in weed population and growth have a direct effect on the reduction in crop yields.

2.2.4.1. Sunflower

Unchecked weed growth during its critical period of crop growth will reduce the yield of sunflower drastically. The decrease in yield due to the presence of weeds was mainly brought about by decreased head size and seed size in sunflower (Johnson, 1971). Gouda *et al.* (1985) observed more than 50% yield reduction when weeds were allowed to grow up to harvest of sunflower. Singh and Singh (1978) reported that weed free situation gave an yield of 17.11 q/ha as against unweeded check. A three fold increase in grain yield was recorded by Reddy *et al.* (1992) in sunflower when plots were kept weed free upto its critical period of 45 days after sowing.

2.2.4.2. Maize

The depressing effect of weeds on crop yields varies with types of weeds, intensity and duration of weed infestation. Young *et al.* (1984) stated that *Agropyron repens* at a density of 745 shoots/m² reduced maize grain yield by 37%. *Echinochloa crusgalli* at a density of 100 plants/m² reduced the yield of maize by 18% (Kropff *et al.*, 1984). Maize yield was reduced by 80 per cent when the fields were infested with *Rottoboellia exaltata* (Sharma and Zelaya, 1986). According to Tiwari *et al.* (1987) maize grain yield was reduced by 100% due to the uncontrolled weed competition under maize-cowpea inter cropping system. However, Rola and Rola (1992) reported that the presence of *Amaranthus retroflexus* in maize fields reduced grain yield by 20 and 32 per cent with 20 and 30 weeds/m². Whereas, Vargessel *et al.* (1994) opined that the weed distribution in corn field was not a critical consideration in determining yield loss. However, Amador Ramirez (1995) registered higher grain yield with an

yield loss. However, Amador Ramirez (1995) registered higher grain yield with an increase in the weed free period. Similarly, Virender Sardana (1997) observed that weeds constitute a serious negative factor in crop production, result in a loss of crop yield by 10 to 15% or more.

2.3. WEED MANAGEMENT METHODS

Minimizing the weed infestation for attaining the remunerative crop yield forms the primary component of weed management. Weed control aims at limiting unwanted plants growth, both in space and time, without any attempt to eliminate the same from the field environment. Efficiency of different weed management methods could be effectively obtained by employing each method at appropriate way and in conducive crop ecosystems.

2.3.1 Cultural and mechanical methods

Weed control is one of the most important objectives of cultural operations. These methods include controlling weeds either by manual labour, bullock drawn implements or by power driven machinery.

Sunflower

Mechanical weeding gave 79% control of weeds compared with 36% control for linuron and prometryn in sunflower (Pawlowski and Derylo, 1975). The lowest dry weight of weeds was obtained with higher yield of sunflower in hand weeded plots (Ghosh *et al.*, 1979). Samui *et al.* (1982) and Ion (1988) reported that two to four times higher seed yields than unweeded control could be obtained with two to three hoeings in sunflower. Jayakumar *et al.* (1988) obtained 300 to 500 kg higher seed yield with two hand weeding than unweeded control in sunflower. Similarly, Girijesh and Patil (1989) recorded the highest seed and oil yields of sunflower in hand weeded plots.

Maize

Field trials conducted in Hamirpur district of Himachal Pradesh showed that hoeing and manual weeding twice increased maize grain yields by 0.36 t/ha (Bhopal Singh *et al.*, 1991). At Ranchi, adoption of hand weeding at 20 and 40 days after sowing resulted in minimum weed infestation in maize during rainy season (Saha and Srivastava, 1992). Hand weeding at 20 and 40 days after sowing of rainfed maize gave the highest weed control efficiency and comparable with metolachlor (1.25 kg/ha) sprayed treatments during rainy season in Bajaura region of Himachal Pradesh (Thakur, 1994). Results of the field experiment conducted by Intodia *et al.* (1996) showed that hand weeding significantly reduced the density and dry matter of weeds compared to chemical treatment in maize cultivated on clay loam soils of Chittorgarh region.

2.3.2. Chemical methods

Inadequate weed management is one of the major causes for low yields of crops. The conventional method of weed control through hand weeding is costly and non-available at critical stages. In the case of mechanical weeding, crop plants may get damaged, as they are small and vulnerable to these methods. Herbicidal weed management becomes a competitive and promising way to control weeds, atleast in the first few weeks of crop sowing.

Sunflower

Single herbicide application: Many pre-emergence herbicides are used for effective weed management in sunflower. Maximum seed yield of sunflower with lower weed dry weight was recorded with pre-emergence application of prometryne 1.0 kg/ha (Raju and Sankaran, 1974). In a study on sandyloam soil, pendimethalin 1.0 to 1.5 kg/ha gave excellent weed control (Vitolo *et al.*, 1983). Mehrotra *et al.* (1984) reported that application of 2.0 kg alachlor, nitrofen (TOK E-25) or butachlor 1-2 kg/ha to sunflower gave effective control of weeds and higher yields. Similarly, pre-emergence application of pendimethalin at 1.24 kg/ha gave 80 to 92% control of weeds without any crop damage (Durigan and Motta, 1989). Basavarajappa (1992) observed higher seed yield and lower weed dry weight with pre-emergence application of pendimethalin 1.0 kg/ha than with manual weeding.

Post-emergence directed spray of paraquat 2.0 kg/ha recorded effective weed control and maximum sunflower seed yield (Ghosh *et al.*, 1979). Tei (1986) stated that post-emergence spray of dichlofopmethyl 3.0 kg, fluazifop-butyl 2.5 kg or quazalofop-methyl 1.0 to 1.5 kg/ha gave good control of *Echinochloa* spp. in sunflower. Application of haloxyfop, chlorazifop or xylofop each at 0.6 kg/ha when sunflower plants were at 4 to 5 leaf stage, gave good control of grasses (Woon, 1986). Friensen (1988) observed that post-emergence application of imazamethabenz 0.1 kg/ha applied to sunflower at 2 to 4 leaf stage, gave 90% control of *Sinapis arvensis*, with higher seed yield.

Herbicide mixtures: Most herbicides are unable to control all noxious weed species, consequently use of herbicide mixtures has become a common practice in controlling diverse weed vegetation. Sarno *et al.* (1986) obtained very good control of *Polygonum aviculare*, *Solanum nigrum*, *Lolium temulentum*, *Avena ludoviciana* and *Hordeum vulgare* when metobromuron 0.5 kg + prometryn 1.0kg or flurochloridone 0.5 kg + metolachlor 1.0 kg/ha was applied in combination. Similarly, Bedmar *et al.* (1989) recorded effective control of major weeds like *Digitaria sanguinalis*, *Setaria* spp, and *Brassica campestris* in sunflower with the mixture of acetachlor 1.44 kg + flurochloridone 0.36 kg and flurochloridone 0.24 kg + alachlor 0.48 kg/ha. Combined application of alachlor 2.0 + pendimethalin 1.5 l/ha or alachlor 1.0 + pendimethalin 0.75 l/ha recorded higher seed yields which were comparable with weed free check in sunflower (Malipatil, 1989). Chennappagoudar *et al.* (2000) reported that application of metolachlor 0.5 kg/ha with pendimethalin 0.75 kg/ha proved to be the best combination in reducing weed dry weight at critical stages of crop growth and at harvest in sunflower.

Maize

Pre-emergence herbicides control grassy and broad-leaved weeds in any tropical cereals. Baker and Terry (1991) reported that pre-emergence herbicide use would be appropriate not only for minimizing weed competition, but also for reducing the work load during the peak labour demand period, avoiding at least one or two inter cultivations during the first 3 to 4 weeks of crop growth and control weeds effectively.

Atrazine : According, to Yadav *et al.* (1985) simazine and atrazine at 0.5 and 1.0 kg/ha as pre-emergence application effectively controlled predominant weeds, *Echinochloa colonum* and *Trianthema portulacastrum* and gave significantly higher yield (4137 and 4077 kg/ha, respectively) than the unweeded check (1944 kg/ha) and on par with clean weeded plots (4313 kg/ha) of maize. Pre-emergence application of atrazine 0.5 kg and manual weeding at three and four weeks after sowing reduced the dry weight of weeds viz. *Trianthema portulacastrum* and *Echinochloa colonum* in maize (Balyan and Bhan, 1987). According to Varshney (1990) a two year study, conducted at mid hills of Meghalaya, showed that application of atrazine to maize at 2.0 kg/ha proved to be effective in controlling weeds and enhancing grain yield by 143% (3636 kg/ha) over control (1351 kg/ha). Similarly, Guar *et al.* (1991) also reported that pre-emergence application of atrazine 0.5 kg/ha completely controlled the broad-leaved weeds, however all grassy weeds were not controlled. According to Balyan *et al.* (1994), application of atrazine at 0.25 or 0.5 kg/ha on 7 or 14 DAS proved either equally or more effective than its pre-emergence application against *Trianthema portulacastrum*, *Echinochloa colonum* and *Digera arvensis*. Sher Singh and Rajput (1995) reported that pre-emergence application of simazine (1.0kg/ha) or atrazine (1.0kg/ha) produced maize grain yield equal to that of weed free condition.

Metolachlor: The predominant maize weeds susceptible to metolachlor were *Chenopodium album*, *Phyllanthus niruri*, *Melilotus indica*, *Trianthema spp.*, *Euphorbia spp.*, *Digitaria sanguinalis*, *Amaranthus viridis* and monocots such as *Dactyloctenium aegyptium*, *Eleusine indica*, *Cyperus rotundus*, *Cynodon dactylon* (Dixon *et al.*, 1980; Obugawitch *et al.*, 1980). Corn is usually tolerant to metolachlor, but injury from pre-emergence application has been observed when seedlings were exposed to cool, wet environmental conditions before emergence (Viger *et al.*, 1991). Application of metolachlor 1.0 to 1.25 kg/ha proved more effective in reducing crop weed competition as was observed by Thakur (1994). Pre-emergence application of metolachlor at 1.25 kg/ha produced the highest mean grain yield of 5.59 t/ha followed by 5.45 t/ha with 1.25 kg atrazine/ha as pre-emergence spray (Rout and Satapathy, 1996). According to Yenish *et al.* (1996) pre-emergence application of metolachlor increased crop yield averaging between 16 and 100% greater than the unweeded control, depending on the year and location.

2.3.3. Integrated weed management

Integrated weed control is a weed population management system that use all suitable techniques in a compatible manner to reduce weed population and maintain them at levels below those causing economic injury to crop cultivation.

Sunflower

Efficient weed control and maximum seed yields of sunflower have been obtained with the application of either alachlor 1.0 kg/ha or eptam 0.5kg/ha as pre-emergence spray along with one hand weeding at 30th day after sowing (Yogeshwara Rao, *et al.*, 1973). Chikulaev (1977) obtained the best weed control with pre-sowing incorporation of prometryne 2.5 kg/ha followed by post-emergence harrowing. Jayakumar *et al.* (1988) reported that maximum seed and oil yields could be obtained with the application of fluchloralin 0.75 kg/ha as pre-emergence spray followed by hand weeding at 30 DAS. Similarly, good control of *Trianthema portulacastrum*, *Amaranthus* spp, *Dactyloctenium aegyptium* and *Echinochloa colonum* was observed by using fluchloridone 0.5 kg as pre-emergence application followed by hand weeding at 30 DAS or pendimethalin 1.0 kg/ha followed by hand weeding at 40 DAS (Nalayini 1990). Legha *et al.* (1992) indicated that higher seed yields could be obtained by pre-emergence application of pendimethalin at 1.0 kg/ha followed by one hand weeding at 40 days after sowing than pendimethalin alone even with increased doses. Wahab *et al.* (2000) reported that pre-emergence application of oxyfluorfen 0.30 kg/ha + one hand weeding at 30 DAS recorded the lowest weed dry matter production and showed higher weed control efficiency. Higher seed yield of 1388 kg/ha was obtained with application of fluchloralin 1.5 kg/ha with one hand weeding at 30 days after sowing and also gave higher weed control efficiency of 96.58 % (Balasubramanian *et al.*, 2000). Sridhar (2001) registered highest seed yield with two inter cultivations + two hand weedings at 25 and 45 days after sowing, followed by pendimethalin + one hand weeding, pendimethalin alone and butachlor + one hand weeding all of which were on par with each other in recording better weed control efficiency.

Weed control, corn yield and economic returns were generally higher in treatments containing herbicides and mechanical weeding than using only mechanical measures (Mulder and Doll, 1993). Integrated weed management with pre-emergence application of atrazine at 0.25 kg/ha with a follow up hand weeding on 40-50 DAS recorded better weed control with higher (3077 kg/ha) yields in rainfed maize (Kandasamy *et al.*, 1998). Chinnusamy *et al.* (2000) reported that integrated weed management with atrazine 0.25 kg/ha followed by one hand weeding at 35 DAS recorded the least weed count both at 20 and 35 DAS in maize. Combination of non-chemical weed control methods of power tiller drawn sweep weeding + hand weeding found to be an effective and economic method of weed control in rainfed maize (AICRP-WC, 2000). Integrated weed control measures with pre-emergence herbicide like alachlor or atrazine or pendimethalin at 1.0 kg/ha combined with post-emergence manual weeding or directed spraying of paraquat (0.50 kg/ha) resulted in higher grain yield of maize with better weed control efficiency (Pandey *et al.*, 2001). Trivedi *et al.* (2002) reported that significantly higher yields in maize could be recorded with alachlor 1.0 kg/ha + hand weeding on 30 and 60 DAS which was on par with weed free treatment.

2.4. EFFECT OF PREPARATORY TILLAGE

Tillage helps in controlling weeds by burying weed seeds and emerged seedlings leaving a rough surface to hinder weed seed germination, expose underground parts of perennial weeds leading to desiccation. Generally ploughs are used for primary tillage. Indigenous plough opens the soil but there will be no inversion. Mould board ploughs are used where soil inversion is necessary. Disc ploughs turn the furrow slice to one side with a scooping action. Cultivator cuts and pulverises the soil, altering weed seed distribution and weed population differently in different soil layers. It is widely recognised that primary tillage influences distribution of weed seed in different soil tillage layers (Fray *et al.*, 1978; Froud-Williams *et al.*, 1983). They also observed that inversion tillage such as mould board ploughing resulted in burial of large proportion of weed seeds in tillage layer. Non inversion tillage methods such as chisel ploughing leave a greater proportion of weed seeds near

the surface. Mould board ploughing turns seed up to the surface at the same time it buries other seed. Ball and Miller (1990) reported that secondary tillage such as row cultivation caused little soil disturbance than primary tillage, which resulted in lesser influence on the seed bank than from primary tillage.

2.4.1. Weed flora

Knowledge on the weed flora will provide useful information to improve the weed management strategies in the particular ecosystem. *Paspalum distichum* consistently declined in direct seeded rice as the number of harrowings increased (De Datta, 1981). New tillage practices such as reduced, minimum or non-tillage commonly caused changes in the composition and abundance of weed species present in the cropping system (Froud-Williams *et al.*, 1981; Gebhardt *et al.*, 1985; Ball and Miller, 1990). However, in some cases, tillage had no selective influence on weed flora (Swanton *et al.*, 1993). According to Cardina *et al.* (1991) common lambsquarters constituted 34 to 93% of the total seed bank in conventional tillage and mould board tillage than in no tillage. Similarly, Buhler (1992) stated that horse weed was dominant in no tillage and ridge tillage plots, whereas green foxtail and red root pigweed were higher in proportion in chisel ploughed and no tilled plots than in the conventional tillage treatments.

Weed population shifts towards annual weeds were observed when conventional tillage systems were changed to non-tillage systems in maize (Ball and Miller, 1993). Thomas and Brenda (1993) reported that on average, reduced tillage fields had more common lambsquarters and green foxtail, no tillage fields had more red root pigweed, crabgrass, yellow fox tail, yellow nut sedge, volunteer corn and velvetleaf than did conventional tillage fields. Common lambsquarters, redroot pigweed, were predominant in both conventional and reduced tillage systems (Lindwall *et al.*, 1994). Kandasamy and Krishnakumar (1997) observed that the effect of summer ploughing in reducing the sedges which are more persistent weeds was more pronounced. They also reported that tractor and power tiller puddling controlled most of the weeds except broad-leaved weeds in rice. Barberi and Cascio (2001) observed that relative abundance index of *Amaranthus* spp. was the highest in no tillage and the lowest in chisel ploughing plots, whereas the opposite situation

occurred for *Conyza canadensis*. They further reported that the total seedlings of *Bilderdykia convolvulus* and *Chenopodium* spp. were higher in mould board ploughed plots than minimum and chisel ploughed plots. Tuesca *et al.* (2001) reported that the weed spectrum changed rapidly in non-tillage systems with increase of annual grassy weed population in maize-soybean as against wind dispersed weeds in wheat-soybean cropping system and inconsistent behaviour of perennial weeds in relation to tillage systems.

2.4.2. Weed density

An important consideration when assessing the feasibility of agronomic practices is that the effect of cultivation system on weed population dynamics. Change in preparatory tillage practices can cause shift in weed species and densities. Green foxtail populations were similar under zero and conventional tillage in wheat (Miller and Nalewaja, 1985). Cardina *et al.* (1991) found in a 20-year tillage experiment that greatest weed seed density was in no-tillage plots and the lowest in conventional tillage plots. Similarly, Teasdale *et al.* (1991) found that total weed density was the greatest after one year in no-tillage and two years in conventional tillage. Populations of several annual grasses including giant foxtail (Buhler and Mester 1991), green foxtail and yellow foxtail (Forcella and Lindstrom, 1988) increased faster in reduced tillage than in conventional tillage systems over years.

The density of certain annual weeds such as kochia, common lambsquarters, redroot pigweed, hairy night shade and green foxtail were found to increase rapidly after chisel ploughing compared to mould board ploughing (Ball and Miller, 1992). Yenish *et al.* (1992) ranked tillage systems for total weed density as chisel ploughing > no-tillage > mould board ploughing. Conservation tillage increased the density of perennial sowthistle, canada thistle, some annual grasses and volunteer crops (Derksen *et al.*, 1993). Similarly, Lindwall *et al.* (1994) reported that grass species including wild oat and green foxtail have had a more variable response to tillage. Dandelion and perennial sow thistle densities increased slightly over years in the minimum and zero tillage treatments (Blackshaw *et al.*, 1994). Vencill and Banks (1994) reported that common ragweed, common lambsquarters, horseweed and sickle pod seed densities were greater in no tillage than conventional tillage and they also observed higher

densities of common cocklebur and large crab grass in conventional tillage than no-tillage plots. Seed bank populations of common lambsquarters with mould board ploughing were greater than those with ridge till and no-till (Clements *et al.*, 1996). Sathyamoorthi *et al.* (2001) reported that primary tillage with country plough resulted in lower densities of grasses and sedges, whereas, broad leaved weed population was reduced by tractor drawn disc or mould board plough followed by cultivator tillage in maize fields raised in black clay and red sandy loam soils.

2.4.3. Weed control

Each type of preparatory tillage varies in its efficiency to control weeds. Seed bank decline was more rapid in mould board ploughing than in chisel ploughing. Control of giant foxtail was lesser under no-till or chisel plough conditions than conventional tillage (Ball, 1992). According to Buhler (1992), red root pigweed and green foxtail were often more difficult to control in chisel ploughing and no tillage than in conventional tillage and reduced tillage. Whereas, Kandasamy and Krishnakumar (1997) reported that summer ploughing reduced the dry weight of weeds in rice fields. Total number of weeds was the highest with the no tillage system and decreased in the plot where soil disturbance occurred (Darodo *et al.* 1999). Chinnusamy *et al.* (2000) reported that disc ploughing followed by cultivator tillage recorded the least dry matter production by weeds, whereas country plough tillage was found to record maximum weed dry matter in black clay loam soils.

2.4.4. Crop yield

Deep tillage with out stubble mulch gave significantly higher grain yield of wheat (Rai and Yadav, 1979). Mahli *et al.* (1988) found that zero tillage resulted in lower yields than conventional tillage in barley, however this was reported in contrast to the findings of Mahli and Nyborg (1990) and Mc Andrew *et al.* (1994) who recorded higher yields with minimum tillage. However, crop yields were affected by tillage induced changes in soil chemical and physical parameters and yields were higher with non-tillage than with conventional tillage systems (Carefoot *et al.*, 1990). Corn yields were not affected by tillage systems (Buher and Daniel, 1988; Buhler, 1992). Vencil and Banks (1994) observed that sorghum grain yields were higher with no tillage system when

it was combined with high degree of weed management than in conventional tillage system. Both corn and soybean yields were greater in mould board ploughing than in conventional ploughing and no tillage (Mulugetta and Stoltenberg, 1997). Kandasamy and Krishnakumar (1997) reported that tractor and power tiller puddling increased the grain yield in rice. Higher grain yield of maize was recorded by disc ploughing followed by cultivator tillage (Chinnusamy *et al.*, 2000). Dheer Singh and Tripathi (2001) recorded the highest grain yield of rice was recorded in the plot puddled by rotavator and lowest in direct sown unpuddled soil. Whereas, Sathyamoorthi *et al.* (2001) recorded higher grain and stover yields of maize raised with disc ploughing followed by cultivator tillage in black clay loam and red sandy loam soils.

2.5. EFFECT OF CROP SEQUENCE ON WEEDS

Cropping sequence influences weed intensity weed flora composition, weed density and their proportion in cultivated fields. Certain weeds are closely associated with particular crops or cropping sequence. Crop rotation introduces conditions and practices that are not favourable for a specific weed species and thus growth and reproduction of that species are hampered.

2.5.1. Weed flora

Green foxtail and wild oat densities increased in continuous mono cropping of wheat (Fay, 1990). Similarly, Hume *et al.* (1991) reported that continuous cropping with wheat could result in build up of certain weed species such as green foxtail. Biswas and Das (1993) reported that shift of weed flora from annuals to perennials (*Cyperus rotundus*) in Jute when it is rotated with rice-wheat system. Dense infestation of downy brome was observed in the continuous winter wheat rotation than wheat-fallow, wheat-lentil and wheat-canola systems (Blackshaw *et al.*, 1994). Shift of weed flora from dicots (*Trianthema monogyna*, *Commelina bengalensis*) in the first year to monocots (*Phalaris minor*) in second year was noticed by Ahuja and Yaduraju (1995) in pigeonpea-wheat system. Stevenson *et al.* (1997) reported that the densities of shepherd's purse and chick weed were much greater in the barley-forage rotation compared to barley monoculture. Repeated weeding for the entire crop season reduced the population of *Commelina benghalensis* during first year, *Brachiaria ramose* in

second year and *Echinochloa colonum* in third year of maize-wheat rotational cropping in North Western Himalayas (Pandey *et al.*, 1999). Similarly, Saikia and Pandey (1999) reported weed flora shift from dicots like *Trianthema portulacastrum* in first year to monocots like *Digitaria sanguinalis* in the second year during rainy season in maize-chick pea cropping system.

2.5.2. Weed density

Continuous corn filed led to record 25 weed seeds/m², but only four weed seeds/m² were recorded when corn was grown in rotation with soybean (Forcella and Lindstrom, 1988). Green foxtail densities were significantly higher even after one year with continuous cropping compared to wheat-fallow rotation (Hume, 1982, Hume *et al.*, 1991). Ball (1992) reported that the seed bank of a three year continuous corn crop was dominated by one annual grass and two annual broad leaf weed species and that a three year continuous pintobean (*Phaseolus vulgaris* L.) rotation had a larger weed seed bank dominated by four annual broad leaf species. The density of broad-leaved weeds increased slightly in jute and when potato was included in jute-rice-wheat sequence (Biswas and Das 1993). Similarly, Liebman and Dyck (1993) stated that monoculture can lead to a less diverse and more intractable weed flora than does crop rotation. Blackshaw *et al.* (1994) observed that lesser weed density in winter wheat-fallow than continuous winter wheat, winter wheat-lentil or winter wheat-canola rotations. The crop rotations that included one to three year of forage production resulted in higher densities of annual broad leaf and perennial weeds in the succeeding potato crop (Liebman *et al.*, 1996). Similarly, Stevenson *et al.* (1997) reported that total weed density in the barley-forage rotation was about three times as that in the barley monoculture. Subsequently, Pandey *et al.* (1999) recorded reduced density of broad-leaved and grassy weeds with repeated weedings or herbicidal management with atrazine and pendimethalin in maize-wheat rotation. Similarly, Saikia and Pandey (1999) recorded lower total weed population due to hand weeding or herbicide treatments in maize-chick pea cropping system.

2.5.3. Weed control

Crop rotation with corn-cotton cropping reduced the Johnson grass much better than a continuous corn rotation (Dale and Chandler, 1979). Gill and Brar, (1985) reported that maize- wheat rotation showed gradual build up of wild oats in wheat. Whereas, in Nebraska, rotating corn and grain sorghum with a broad leaf crop was an effective method of controlling shattercane (*Sorghum bicolor* L.), because it allowed for the use of herbicides which are phytoactive on cereals (Francis and Clegg, 1990). Ponnuswamy *et al.*, (1996) reported that the yields of both crops were increased in a sorghum-cotton sequence due to the herbicide rotation Hanumanthappa *et al.* (2001) recorded lesser infestation of Orobanche when tobacco rotated with groundnut + redgram cropping.

2.6. EFFECT OF PREPARATORY TILLAGE AND WEED MANAGEMENT METHODS

Differential rates of change among weed species in the seed bank will eventually be expressed as change in weed flora. Management practices such as preparatory tillage and weed control influence the rate of change in individual weed species and in the seed bank.

Weeds could be effectively controlled with a minimum tillage when combined with the use of herbicides, but total elimination of tillage may not be feasible (Hume *et al.* 1991). Summer ploughing and pre-emergence application of butachlor or anilophos followed by one hand weeding on 30 days after transplanting were found to control weeds effectively and to register higher grain yield in rice (Alwar Arunachalam *et al.*, 1992). Mulder and Doll (1993) reported that greater weed control, crop yield and economic returns were obtained in maize with treatments combining pre-emergence application of atrazine 1.8 kg ai/ha + metolachlor 2.2 kg ai/ha with mechanical weeding than chemical method alone. Reduced herbicide inputs plus inter row cultivation were as effective as full rate herbicide inputs for the management of several annual weed species (common lambsquarters, giant foxtail and redroot pigweed) in both conventional and conservation tillage systems (Mulugetta and Stoltenberg, 1997). It was observed that puddling with power tiller or tractor cage wheel, supplemented with either hand weeding twice or application of butachlor

1.5 kg/ha + hand weeding, was found to be the most economic weed management method in a transplanted lowland rice-rice sequence (Kandaswamy and Krishnakumar, 1997). Sathyamoorthi *et al.* (2001) reported that higher maize grain yield with better economic returns could be achieved by land preparation with tractor drawn disc plough followed by cultivator tillage combined with integrated weed management of pre-emergence application of atrazine 0.25 kg/ha followed by one hand weeding.

From the foregoing review, it could be synthesized that the weed flora vary widely with different soil and crop environment and the weed population dynamics also greatly altered by different management practices. Pre sowing land preparation with different tillage methods and weed management by chemical, manual and mechanical means result in recording differential weed competition and crop growth and yields of individual crops. Hence, an attempt on the influence of different preparatory tillages and weed management methods on weed population dynamics and on the yield of individual crops would pave way for higher productivity of the system.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

Field experiment was conducted at Eastern Block farm, Department of Agronomy, Tamilnadu Agricultural University, Coimbatore during *kharif* and *rabi* seasons 2001–2002 to study the weed population dynamics in sunflower–maize cropping system as influenced by preparatory tillage and weed management methods. The details of materials used and the methods adopted during the course of the study are presented in this chapter.

3.1. EXPERIMENTAL MATERIALS

3.1.1. Location

The experiment was conducted in Field No.69 of the Eastern Block farm, Tamil Nadu Agricultural University, Coimbatore, situated at 11° North latitude and 77° East longitude and at an altitude of 427 m above the MSL.

3.1.2. Climate and weather

The normal climatic conditions of the location (mean of 63 years) are as follows. The mean annual rainfall of Coimbatore is 657 mm distributed over 47 rainy days. The annual mean maximum and minimum temperatures are 31.5 and 21.4°C, respectively. The relative humidity ranges from 61 to 91% in the forenoon and 14 to 68% in the afternoon. The mean bright sunshine hours per day are 7.4 hours with a mean solar radiation of 429 cal/cm²/min. The weather conditions prevailed during the cropping period from July 2001 to February 2002 are presented in Appendix I and depicted in Fig .1. During the cropping period, the maximum and the minimum temperatures ranged from 33.6°C to 17.0°C. The total rainfall received during the cropping period was 442.4 mm in 28 rainy days.

3.1.3. Soil characteristics of the experimental field

The soil of the experimental field was sandy clay loam in texture. The soil was low in available Nitrogen and Phosphorus and high in available Potassium. The physical and chemical properties of the soil are given in the Table 1.

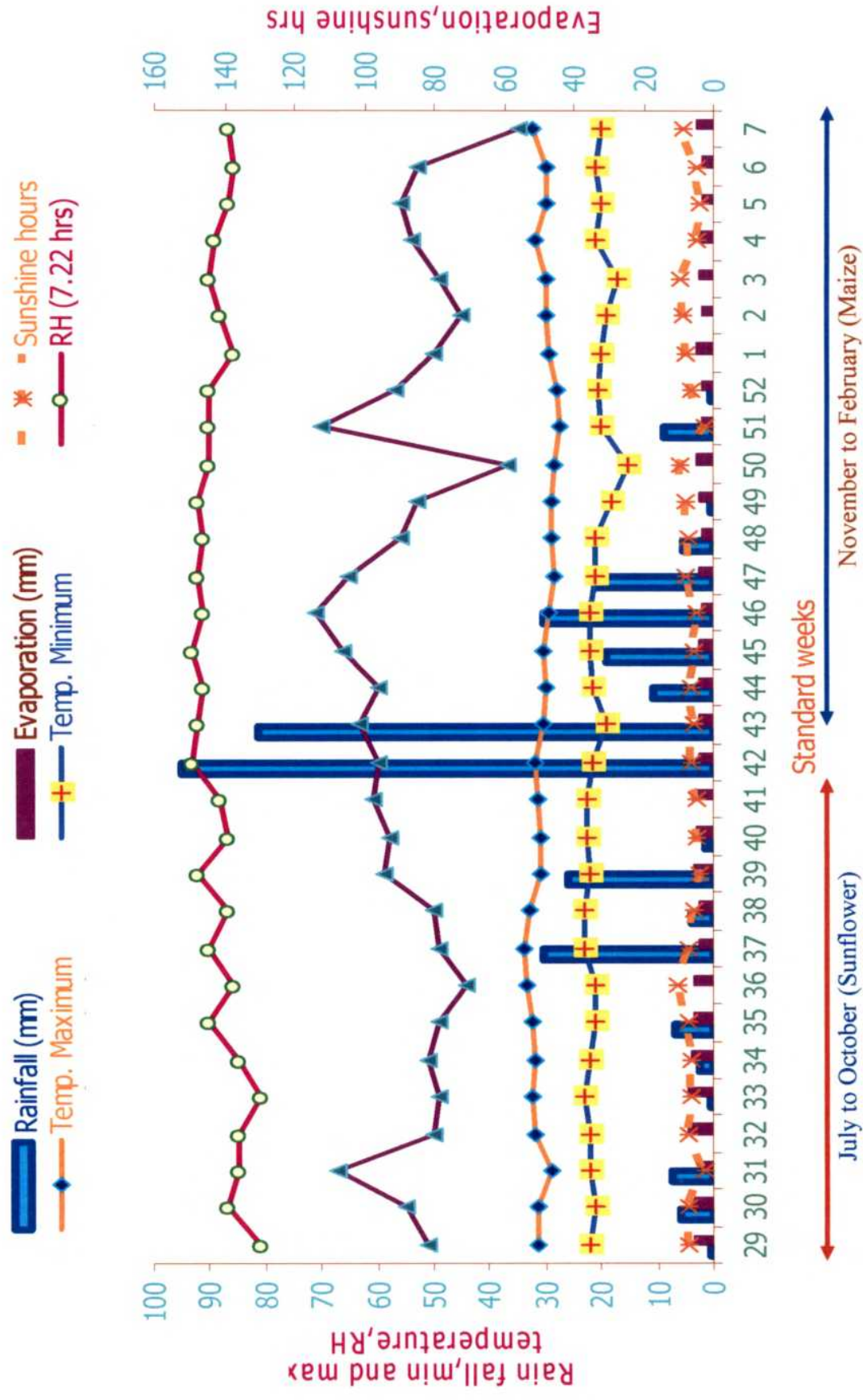


Fig 1. Weather parameters prevailed during the cropping period

Table 1. Soil characteristics of the experimental field.

Properties	Composition
A. Mechanical Analysis	
1. Clay	32.1%
2. Silt	18.3%
3. Coarse sand	29.2%
4. Fine sand	19.5%
5. Texture	Sandy clay loam
B. Chemical Analysis	
1. Available Nitrogen (kg/ha)	196.10
2. Available Phosphorus (kg/ha)	9.33
3. Available Potassium (kg/ha)	275.56
4. Electrical Conductivity (ds/m)	0.3
5. pH (1:2 Soil water solution)	8.0

3.1.4. Season

The first crop sunflower was raised during *kharif* (July-October) and the second crop maize during *rabi* (Nov-Feb) seasons of 2001-2002.

3.1.5. Crops and Varieties

Sunflower variety CO-2 (Plate 1.) with a duration of 90 days and maize variety CO-1 maturing in 105-110 days were selected for this study. The seeds were obtained from the Central farm, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore

3.2. EXPERIMENTAL METHODS**3.2.1. Design and layout**

The experiment was laid out in strip plot design comprised of five preparatory tillage methods in main plots and four weed management methods in sub plots. The treatments were replicated thrice. The field layout plan is depicted in Fig .2.

Early growth stage



Blooming stage



Plate 1. General view of the experimental field

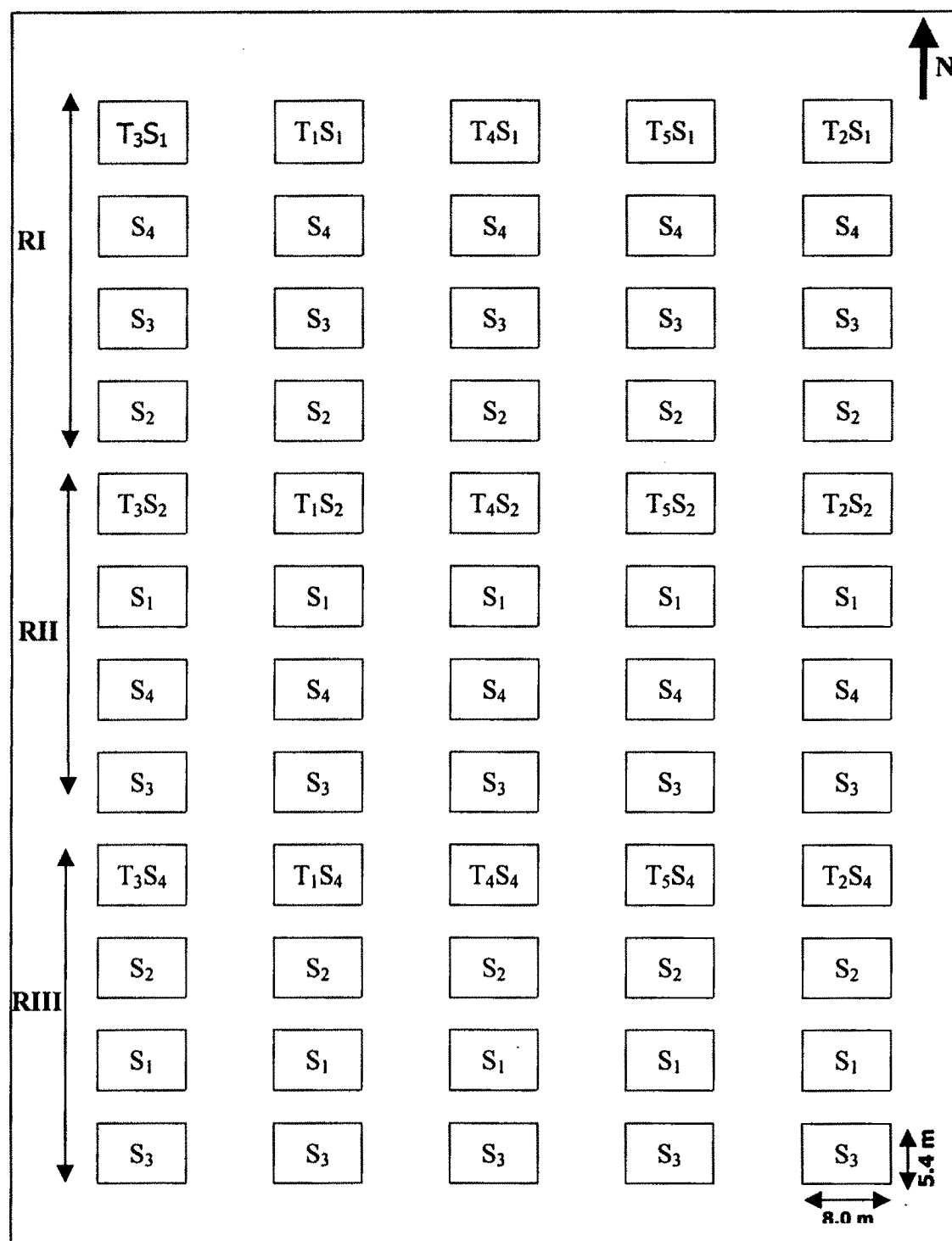


Fig. 2. Lay-out plan of the experimental field

3.2.2. Treatment details

Main Plots (Preparatory Tillage methods*)

- T₁ – Country plough tillage (Two Ploughings)
- T₂ – Cultivator tillage (Two ploughings)
- T₃ – Mould board ploughing + Cultivator tillage (Two ploughings)
- T₄ – Disc ploughing + Cultivator tillage (Two ploughings)
- T₅ – Minimum tillage (No ploughing)

Subplots (Weed management methods)

<i>Sunflower</i>	<i>Maize</i>
W ₁ – Hand weeding on 20 and 40 DAS	Hand weeding on 20 and 40 DAS
W ₂ – Pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha + HW on 40 DAS	Atrazine 0.25kg/ha + HW on 40 DAS
W ₃ – Mechanical weeding with rotary weeder on 20 and 40 DAS	Mechanical weeding with rotary weeder on 20 and 40 DAS
W ₄ – Unweeded control.	Unweeded control.
* Only during sunflower cropping	

3.2.3. Plot Size

The individual experimental plot size was 8m x 5.4 m (gross plot) and 7.2 m x 3.0 m (net plot) in dimension. Two rows on either side were utilized for collecting destructive samples for growth analysis and nutrient uptake studies.

3.3. CROPPING DETAILS

3.3.1. Field preparation

Sunflower

The field was ploughed as per the treatment schedule. Ridges and furrows were formed at 60 cm apart with ridge plough and rectified manually.

Maize

After the harvest of the sunflower crop, the stubbles were collected and the field was cleaned and the ridges and furrows were rectified manually before maize sowing.

3.3.2. Fertilizer application***Sunflower***

Farm yard manure at 12.5 t/ha was incorporated uniformly over the field at last ploughing. Before sowing, the recommended fertilizer dose of 40:20:20 kg NPK/ha was applied in the form of Urea, Single Super Phosphate and Muriate of Potash basally by the side of the seed rows.

Maize

The recommended dose of 135: 62.5: 50 kg NPK /ha was applied. Twenty five per cent of the recommended N and full dose of P_2O_5 and K_2O were applied basally. Half the dose of N was top dressed at 25 DAS and the remaining 25 percent at 45 DAS.

3.3.3. After cultivation**3.3.3.1. Thinning and gap filling**

Gap filling was done on 8 DAS for sunflower and on 7 DAS for maize. Thinning was done on 12 DAS for sunflower and on 10 DAS for maize leaving a single healthy seedling per hill.

3.3.3.2. Irrigation

First irrigation was given at the time of sowing and the life saving irrigation on third day after sowing. The subsequent irrigations were scheduled at 7-10 days interval depending upon the rainfall. Irrigation was withheld 15 days before harvest.

3.3.3.3. Weed management

Weed management was done as per the treatment schedule. For manual weeding treatments, two hand weeding were given on 20 and 40 DAS. Herbicide treated plots were

applied with a mixture of pendimethalin 0.50 kg/ha + metalochlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize as pre-emergence spray on third day after sowing followed by a hand weeding on 40 DAS. For mechanically weeded plots, two weeding were given on 20 and 40 DAS with peg type rotary weeder in between rows and within the rows weeds were removed manually.

3.3.3.4. Plant protection

Sunflower

Spraying of Endosulfan 35% EC 1000 ml/ha on the 30th day of sowing against leaf caterpillar and weevils as a prophylactic measure.

Maize

Spraying of Quinalphos 25% EC 1000 ml/ha on the 20th day of sowing against stem borer, weevils and aphids as a prophylactic measure.

3.3.4. Harvesting and threshing

Sunflower

Harvesting of sunflower was done at 90 DAS. The heads from the net plot area were cut at its base, sun dried, threshed and cleaned. The seed yield was accounted from the net plot after drying to 14-16 % moisture level.

Maize

The cobs harvested from each treatment net plot area were sun dried, threshed, cleaned and grain yield was recorded at 12 % moisture level. After harvest of the cobs, the stover from each plot was cut close to the ground level and left in the field for three days for sun drying and weighed for stover yield.

3.4. OBSERVATIONS RECORDED

A. Weed observations

3.4.1. Weed characters

Weed characters were studied at 30, 60 DAS and at harvest stages of the crops.

3.4.1.1. Weed flora

Predominant weed species in unweeded control were observed, identified and grouped as grasses, sedges and broad-leaved weeds and presented as dominant weed flora of the experimental field.

3.4.1.2. Weed density

Weed population in each plot were recorded by using quadrat (0.5 m X 0.5 m) in four places at random and expressed as number/m² (Burnside and Wicks, 1965). Predominant individual weeds, grasses, sedge and brood leaved weeds present in each plot were recorded separately and expressed in No/m².

3.4.1.3. Weed relative density

Relative density of individual predominant weed species and group wise weeds was worked out as detailed below and expressed as percentage.

$$\text{Relative density (RD \%)} = \frac{\text{Absolute density of a given species (No./m}^2\text{)}}{\text{Total absolute density of all species (No./m}^2\text{)}} \times 100$$

3.4.1.4. Weed dry matter

The weeds removed from each treatment plot at every sampling time were air dried and then oven dried to obtain a constant weight at 80° ± 2° C and expressed as kg/ha.

3.4.1.5. Weed control efficiency

Weed Control Efficiency (WCE) was calculated as per the procedure given by Mani *et al* (1973) and expressed in %.

$$\text{WCE (\%)} = \frac{\text{WDC} - \text{WDT}}{\text{WDC}} \times 100$$

Where,

WDC – Weed dry weight in unweeded control plot (kg/ha)

WDT – Weed dry weight in treated plot (kg/ha)

3.4.1.5. Weed index

Weed Index (WI) expresses the competition offered by weeds as measured by percentage reduction in yield owing to their presence in the field. The WI was calculated by the following formula as suggested by Gill and Vijay Kumar (1969).

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

Where,

X = Yield (kg/ha) from minimum weed competition plot (maximum yield)

Y = Yield (kg/ha) of treatment plot for which the weed index is to be worked out.

B. Crop observations

3.4.2. Growth parameters

3.4.2.1. Plant height

Sunflower

Plant height was measured from the base of the plant to the growing tip at 30 DAS and to the capitulum at 60 DAS and at harvest and expressed in cm.

Maize

Plant height was measured from the base to the tip of the longest leaf on 30 and 60 DAS and at harvest and expressed in cm.

3.4.2.2. Dry matter

Dry matter production was estimated at 30, 60 DAS and at harvest for the crops. Five plants were removed from the sample rows, air dried and then oven dried at $80^{\circ} \pm 2^{\circ}\text{C}$ till a constant weight was recorded. Dry matter production was expressed in kg/ha.

3.4.3. Physiological parameters

3.4.3.1. Leaf area index

Sunflower

From five randomly selected plants in each treatment plot observation was made for leaf length and width and number of leaves per plant on 30, 60 DAS and at harvest stage. From these observations, Leaf Area Index (LAI) was calculated using the formula given by Rawson *et al* (1980).

$$\text{LAI} = \frac{L \times W \times K \times N}{S} \times 100$$

Where,

- L - Length of the leaf from top (cm)
- W - Maximum width of the leaf blade (cm)
- K - A constant factor of 0.73
- N - Number of leaves per plant
- S - Land area occupied (cm^2)

Maize

From five randomly selected plants in each treatment plot observation was made for leaf length and width and number of leaves per plant on 30, 60 DAS and at harvest stage. From these observations, LAI was calculated using the formula given by McKee (1964)

$$\text{LAI} = \frac{L \times W \times K \times N}{S} \times 100$$

Where,

- L - Length of the leaf blade (cm)
- W - Maximum width of the leaf blade (cm)
- K - A constant factor of 0.76
- N - Number of leaves per plant
- S - Land area occupied (cm²)

3.4.3.2. Growth analysis

Growth analysis such as crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) were worked out between different stages as described by Watson (1952) and expressed as g/m²/day, g/g/day and mg/cm²/day, respectively.

$$\begin{aligned} \text{CGR} &= \frac{W_2 - W_1}{t_2 - t_1} \\ \text{RGR} &= \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \\ \text{NAR} &= \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e LA_2 - \log_e LA_1}{LA_2 - LA_1} \end{aligned}$$

Where,

- W₁ = Dry weight per unit area at time t₁
- W₂ = Dry weight per unit area at time t₂
- LA₁ = Leaf area (m²) at time t₁
- LA₂ = Leaf area (m²) at time t₂

3.4.4. Yield attributes

Yield attributes of sunflower and maize were recorded at harvest with randomly selected five plants from the net plot area.

*Sunflower***3.4.4.1. Capitulum diameter**

The diameter of the capitulum was recorded in two diagonal directions and the average was taken as the diameter of the head in cm.

3.4.4.2. Capitulum weight

The average weight of individual capitulum from five randomly selected plants was recorded and was expressed in grams.

3.4.4.3. Number of seeds/ capitulum

The average number of seeds in capitulum of five plants were counted and presented as number of seeds per capitulum.

3.4.4.4. Thousand seed weight

The weight of 1000 seeds drawn at random from seed yield of five randomly selected plants was recorded and expressed in grams.

*Maize***3.4.4.5. Cob size**

The length and girth of the cobs from the observation plants were measured and expressed in cm.

3.4.4.6. Cob weight

The average weight of individual cob from five randomly selected plants was recorded and expressed in grams.

3.4.4.7. Number of grains/cob

The average number of grains in cobs of five plants were counted and presented as number of grains per cob.

3.4.4.8. Thousand grain weight

The weight of 1000 grains drawn at random from the grain yield of five randomly selected plants was recorded and expressed in grams.

3.4.5. Yield

Sunflower

Grain yield in each net plot was weighed and expressed in kg/ha.

Maize

Grain yield in each net plot was weighed and expressed in kg/ha. The maize stover in the net plot area was cut, dried and the weight was recorded in kg/ha.

3.4.6. Nutrient analysis

Uptake by crops and removal by weeds

The over dried crop and weed samples were ground in a Wiley mill and analyzed for nutrient contents. The N,P and K uptake by crops and removal by weeds are expressed in kg/ha.

Table 2. Methods used in plant and weed chemical analysis

Estimation	Methodology	Reference
Nitrogen	Micro Kjeldhal digestion	Humphries(1956)
Phosphorus	Triple acid digestion with Calorimetry method	Jackson (1973)
Potassium	Triple acid digestion with flame photometry method	Jackson (1973)

3.5. SYSTEM PRODUCTIVITY

3.5.1. Weed and crop dry matter

Weed and crop dry matter at each stage of observation was combined for both the crops and presented as system weed dry weight and plant dry matter production in kg/ha, respectively.

3.5.2. Productivity

Sunflower seed yield was converted in to maize grain equivalent yield as detailed below.

$$\text{Maize grain equivalent yield} = \frac{\text{Sunflower yield (kg/ha)}}{\text{Unit price of maize (Rs./kg)}} \times \text{Unit price of sunflower (Rs./kg)}$$

Maize grain equivalent yield of both the crops was calculated and presented as the system productivity in kg/ha.

3.6. ECONOMICS ANALYSIS

The expenditure incurred from sowing to harvest was worked out for both crops and expressed in Rs/ha. Total income obtained from grain for sunflower and from grain and stover yields for maize were calculated for individual treatments. Gross and net returns and benefit-cost ratio and per day returns using crop yield duration were worked out based on total variable cost and returns. Economic parameters viz. gross returns, net returns, B:C ratio and per day return were worked for individual crops and for the cropping system.

3.6.1. Gross returns

Gross returns were calculated using grain yield for sunflower and grain and stover yields for maize based on market price and expressed as Rs./ha.

3.6.2. Net returns

Net returns were calculated by deducting the variable cost of cultivation from gross returns as detailed below and presented in Rs./ha.

$$\text{Net returns (Rs./ha)} = \text{Gross returns (Rs./ha)} - \text{Variable cost of cultivation (Rs./ha)}$$

3.6.3. Benefit-cost ratio

Benefit-cost ratio was calculated based on gross returns and variable cost of cultivation as given

$$\text{Benefit-cost ratio (B: C ratio)} = \frac{\text{Gross returns (Rs./ha)}}{\text{Cost of cultivation (Rs./ha)}}$$

3.6.4. Per day returns

Per day returns was worked using gross return and the crop field duration and expressed in Rs./ha/day.

$$\text{Per day returns (Rs./ha)} = \frac{\text{Gross returns (Rs./ha)}}{\text{Crop field duration (days)}}$$

3.7. STATISTICAL ANALYSIS

The observed data on weeds and test crops were statistically analyzed based on the procedure given by Gomez and Gomez (1984) to find out the treatment differences. The data on weed count and weed dry weight showed higher variation were subjected to square root transformation before statistical analysis as suggested by Bartlett (1947). Critical differences were worked out at 5% probability level wherever the treatment differences were significant.

RESULTS

CHAPTER IV

RESULTS

The results of field experiments conducted at the Eastern block farm, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during *kharif* and *rabi* seasons of 2001-2002 to study the weed population dynamics and productivity in sunflower-maize cropping system as influenced by preparatory tillage and weed management methods are presented in this chapter.

4.1. STUDIES ON WEED CHARACTERS

4.1.1 Weed flora

Weed flora of the experimental field predominantly consisted of ten species of broad-leaved weeds, four species of grasses and a sedge weed (Table 3). The predominant among broad-leaved weeds (Plate 3 & 4.) were *Trianthema portulacastrum*, *Parthenium hysterophorus* and *Digera arvensis*. Among the grassy weeds, *Cynodon dactylon* and *Dactyloctenium aegyptium* were the dominant ones (Plate 2.). *Cyperus rotundus* was the only sedge present.

4.1.2 Individual weed density

4.1.2.1. *Cynodon dactylon*

Sunflower

The density of *Cynodon dactylon* was influenced by both the preparatory tillage and the weed management methods at all the growth stages of sunflower (Table 4). Preparatory tillage either with country plough (T₁) or tractor drawn cultivator twice (T₂) recorded the lowest density of *Cynodon dactylon* at 30 and 60 DAS as well as at harvest. The highest density was recorded with minimum tillage (T₅) at 30 DAS, but the density of *Cynodon dactylon* in T₅ was comparable with that of either mould board (T₃) or disc plough (T₄) combined with cultivator tillage twice, at 60 DAS and it was on par with T₃ only at harvest.

Among the weed management methods, the lowest density of *Cynodon dactylon* was recorded with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha



Chloris barbata



Cynodon dactylon



Dactyloctenium aegyptium



Cyperus rotundus

followed by one hand weeding on 20 DAS (W_2) at all the growth stages of observation. Unweeded check (W_4) recorded the highest density of *Cynodon dactylon* at all the growth stages of sunflower. Comparable density of *Cynodon dactylon* was recorded with hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS at all the stages of observation.

The interaction effect of preparatory tillage and weed management methods was not significant in altering the density of *Cynodon dactylon* at all the growth stages of sunflower.

Table 3. Weed flora of the experimental field

S. No	Botanical Name	Common Name	Habit	Family
A. Grasses				
1.	<i>Chloris barbata</i> , Swasts	Swollen finger grass	A	Poaceae
2.	* <i>Cynodon dactylon</i> , (L.) Pers	Bermuda grass	P	Poaceae
3.	* <i>Dactyloctenium aegyptium</i> , Beaur.	Crow foot grass	A	Poaceae
4.	<i>Panicum repens</i> , L.	Torpedo grass	P	Poaceae
B. Sedges				
5.	* <i>Cyperus rotundus</i> L.	Nut grass	P	Cyperaceae
C. Broad leaved weeds				
6.	<i>Amaranthus viridis</i> , L.	Slender Amaranth	A	Amaranthaceae
7.	<i>Acalypha indica</i> , L.	Copper leaf	A	Euphorbiaceae
8.	<i>Boerhaavia erecta</i> , L.	Crippling spiderling	A	Nyetaginaceae
9.	<i>Corchorus olitorius</i> , L.	Jew's mallow	A	Tiliaceae
10.	<i>Datura stramonium</i> , L.	Thorn apple	A	Solanaceae
11.	* <i>Digera arvensis</i> , Forsk		A	Amaranthaceae
12.	<i>Euphorbia hirta</i> , L.	Pill pod spurge	A	Euphorbiaceae
13.	<i>Euphorbia geniculata</i> L.	-	A	Euphorbiaceae
14.	* <i>Parthenium hysterophorus</i> , L.	Carrot weed	A	Asteraceae
15.	* <i>Trianthema portulacastrum</i> L.	Horse purslane	A	Aizoaceae

A – Annual

P – Perennial

* Predominant weeds



Acalypha indica



Boerhaavia erecta



Corchorus olitorius



Datura stramonium

Table 4. Effect of preparatory tillage and weed management methods on density of *Cynodon dactylon* (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	4.16(23.65)	4.30(22.55)	4.04(18.60)	3.89(20.82)	4.03(19.85)	3.76(16.24)
T ₂	4.12(23.41)	4.14(21.18)	3.86(16.92)	3.78(19.83)	3.82(17.87)	3.53(14.06)
T ₃	4.55(27.12)	4.78(26.81)	4.56(23.11)	4.36(25.00)	4.56(24.55)	4.06(18.65)
T ₄	4.36(24.82)	4.60(25.02)	4.37(21.32)	4.14(23.07)	4.36(22.85)	3.83(16.44)
T ₅	4.76(29.88)	4.76(26.82)	4.61(23.73)	4.73(30.19)	4.70(26.55)	4.14(22.31)
SEd	0.08	0.08	0.10	0.11	0.11	3.10
CD (5%)	0.19	0.20	0.23	0.26	0.25	3.23
W ₁	3.78(15.77)	4.11(18.59)	3.98(17.46)	3.51(13.71)	3.81(16.17)	3.76(15.19)
W ₂	2.24(5.53)	2.97(9.79)	3.61(14.48)	2.15(5.12)	2.87(9.09)	3.09(10.49)
W ₃	3.78(15.79)	4.29(20.25)	4.19(19.40)	3.51(13.64)	3.98(17.46)	3.85(16.37)
W ₄	7.76(66.01)	6.71(49.28)	5.37(31.61)	7.55(62.66)	6.51(46.62)	5.04(28.11)
SEd	0.32	0.21	0.10	0.32	0.21	0.11
CD (5%)	0.66	0.44	0.21	0.65	0.43	0.23
<u>T at W</u> SEd	0.63	0.42	0.22	0.63	0.43	0.24
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	0.72	0.48	0.23	0.71	0.48	0.26
CD (5%)	NS	NS	NS	NS	NS	NS

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods



Digera arvensis



Euphorbia geniculata



Parthenium hysterophorus



Trianthema portulacastrum

Plate 4. Predominant broad-leaved weeds of the experimental field

Maize

Preparatory tillage before sunflower cropping and weed management methods influenced the density of *Cynodon dactylon* significantly (Table 4). The lowest density of *Cynodon dactylon* was recorded either with country plough tillage twice (T₁) or with cultivator tillage twice (T₂) at all the growth stages of maize. The density of *Cynodon dactylon* was the highest in minimum tillage (T₅) at 30 DAS and at harvest. The highest density with T₅ was comparable with mould board ploughing followed by cultivator tillage twice (T₃) at 60 DAS. The density of *Cynodon dactylon* was on par in both mould board tillage (T₃) and disc plough tillage (T₄) followed by cultivator tillage twice, at 30 and 60 DAS of observation as well as at harvest.

In the case of weed management methods, pre-emergence application of atrazine 0.25 kg/ha + one hand weeding on 40 DAS (W₂) resulted in lower density of *Cynodon dactylon* than the other weed management methods. Unweeded control (W₄) recorded the highest *Cynodon dactylon* density. Hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS were on par with each other in reducing the density of *Cynodon dactylon* at all the growth stages of observation.

There was no significant interaction between the preparatory tillage and weed management methods in influencing the density of *Cynodon dactylon* in maize at all the growth stages.

4.1.2.2. *Dactyloctenium aegyptium*

Sunflower

Both preparatory tillage and weed management methods significantly influenced the density of *Dactyloctenium aegyptium* (Table 5). The lowest density was recorded with either country plough tillage twice (T₁) or cultivator tillage twice (T₂) at all the growth stages. Minimum tillage (T₅) registered the highest density of *Dactyloctenium aegyptium* at 30 DAS. However, the density with T₅ was comparable either with that of mould board ploughing (T₃) or disc plough tillage (T₄) followed by cultivator tillage twice at 60 DAS and with that of T₃ alone

Table 5. Effect of preparatory tillage and weed management methods on density of *Dactyloctenium aegyptium* (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	2.80(10.66)	2.90(10.25)	2.72(8.45)	2.65(11.04)	2.74(9.21)	2.56(7.54)
T ₂	2.80(10.90)	2.79(9.63)	2.60(7.69)	2.58(9.21)	2.60(8.29)	2.40(6.52)
T ₃	3.07(12.32)	3.22(12.19)	3.07(10.50)	2.97(11.60)	3.10(11.40)	2.77(8.65)
T ₄	2.95(11.33)	3.10(11.37)	2.94(9.69)	2.82(10.71)	2.97(10.60)	2.61(7.63)
T ₅	3.22(13.59)	3.21(12.19)	3.11(10.78)	3.22(14.00)	3.20(12.32)	3.00(10.35)
SEd	0.05	0.05	0.06	0.07	0.07	0.06
CD (5%)	0.12	0.13	0.15	0.18	0.17	0.16
W ₁	2.56(7.22)	2.77(8.45)	2.68(7.93)	2.39(6.36)	2.60(7.51)	2.52(7.05)
W ₂	1.52(2.55)	2.00(4.45)	2.43(6.58)	1.47(2.37)	1.95(4.22)	2.10(4.87)
W ₃	2.55(7.21)	2.89(9.20)	2.83(8.81)	2.39(6.33)	2.71(8.10)	2.62(7.60)
W ₄	5.23(30.06)	4.52(22.41)	3.62(14.37)	5.14(29.09)	4.43(21.64)	3.43()
SEd	0.21	0.14	0.07	0.21	0.14	0.07
CD (5%)	0.44	0.29	0.14	0.44	0.29	0.16
<u>T at W</u> SEd	0.42	0.28	0.15	0.43	0.29	0.26
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	0.48	0.32	0.15	0.48	0.32	0.17
CD (5%)	NS	NS	NS	NS	NS	NS

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

at harvest. Both T₃ and T₄ were on par in reducing the density of *Dactyloctenium aegyptium* both at 30 DAS and at harvest.

Pre-emergence application of pendimethalin 0.5 kg/ha + metolachlor 0.5 kg/ha followed by one hand weeding (W₂) resulted in lower density of *Dactyloctenium aegyptium*, while unweeded control (W₄) recorded the highest density at all the three stages of observation. Comparable density of *Dactyloctenium aegyptium* was recorded with hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS and was superior to W₄ at all the three growth stages.

The interaction effect between the preparatory tillage and weed management methods was not significant in affecting the density of *Dactyloctenium aegyptium* at all the growth stages of sunflower.

Maize

Significant influence of preparatory tillage and weed management methods was found in altering the density of *Dactyloctenium aegyptium* in maize also (Table 5). Country plough tillage twice (T₁) or cultivator tillage twice (T₂) recorded lower and comparable density of *Dactyloctenium aegyptium* at all the three stages. Minimum tillage (T₅) registered the highest density at all the three stages of maize. Highest density of *Dactyloctenium aegyptium* with T₅ was comparable with mould board ploughing followed by cultivator tillage twice (T₃) at 60 DAS. The density of *Dactyloctenium aegyptium* was comparable in both the preparatory tillage with mould board ploughing (T₃) and disc ploughing (T₄) followed by cultivator tillage twice at all the growth stages of observation.

The lowest density of *Dactyloctenium aegyptium* was observed with pre-emergence application of atrazine 0.25 kg/ha (W₂), while unweeded control (W₄) was found to result in the highest density at all the growth stages of observation. Performance of hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS was comparable and were next to W₂ in reducing the density of *Dactyloctenium aegyptium* at all the growth stages.

Significant interaction effect was not found between preparatory tillage and weed management methods in affecting the density of *Dactyloctenium aegyptium* at any one of the stages.

4.1.2.3. Other grasses

Sunflower

The effect of preparatory tillage and weed management methods was significant in influencing the density of other grassy weeds (Table 6). Lowest density of other grasses was recorded either by country plough tillage twice (T₁) or cultivator tillage twice (T₂) at all the growth stages. However, T₁ was on par with disc ploughing followed by cultivator tillage twice (T₄) and 30 DAS. Highest density of other grasses was recorded by minimum tillage (T₅) which was comparable with mould board ploughing followed by cultivator tillage twice (T₃) both at 30 DAS and at harvest, but T₅ was on par with T₃ and T₄ at 60 DAS. At harvest, the effect of T₃ and T₄ was on par in reducing the density of other grasses in sunflower

In case of weed management methods, pre-emergence application of pendimethalin 0.5 kg/ha + metolachlor 0.5 kg/ha followed by one hand weeding on 40 DAS (W₂) performed better and registered the lowest density of other grasses and unweeded control (W₄) recorded the highest density. Comparable density of other grasses was recorded both with hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS at 30 and 60 DAS of observation in sunflower. Whereas, W₁ was significantly superior to W₃ in reducing the density of other grasses at harvest.

The density of other grasses was not significantly influenced by the interaction effect of preparatory tillage and weed management methods.

Maize

Significant influence was observed both by preparatory tillage and weed management methods in influencing the density of other grasses in maize (Table 6). Country plough tillage twice (T₁) or cultivator tillage twice (T₂) resulted in the lowest density of other grasses at all the growth stages. However, the lowest density in T₁ was comparable with that of disc ploughing

Table 6. Effect of preparatory tillage and weed management methods on density of other grasses (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T₁	2.55(8.98)	2.65(8.59)	2.43(6.76)	2.20(6.69)	2.28(6.37)	2.13(5.22)
T₂	2.48(8.46)	2.63(8.31)	2.32(6.15)	2.14(6.37)	2.66(5.74)	2.00(4.51)
T₃	2.84(10.31)	2.99(10.42)	2.75(8.40)	2.47(8.03)	2.58(7.89)	2.30(5.99)
T₄	2.67(9.35)	2.88(9.73)	2.63(7.75)	2.34(7.41)	2.47(7.34)	2.17(5.28)
T₅	2.92(11.07)	2.96(10.26)	2.78(8.62)	2.68(9.70)	2.66(8.53)	2.50(7.17)
SEd	0.05	0.05	0.06	0.06	0.06	0.05
CD (5%)	0.13	0.12	0.14	0.15	0.14	0.13
W₁	2.30(5.83)	2.58(7.32)	2.40(6.34)	1.99(4.40)	2.16(5.19)	2.09(4.87)
W₂	1.41(2.22)	1.97(4.39)	2.17(5.26)	1.22(1.64)	1.62(2.91)	1.75(3.37)
W₃	2.35(6.09)	2.66(7.79)	2.53(7.05)	1.99(4.38)	2.25(5.61)	2.18(5.26)
W₄	4.72(24.40)	4.10(18.42)	3.23(11.49)	4.28(20.13)	3.69(14.98)	2.85(9.03)
SEd	0.19	0.12	0.06	0.18	0.12	0.06
CD (5%)	0.39	0.25	0.13	0.37	0.24	0.13
T at W SEd	0.38	0.24	0.13	0.35	0.24	0.14
CD (5%)	NS	NS	NS	NS	NS	NS
W at T SEd	0.43	0.27	0.14	0.40	0.27	0.14
CD (5%)	NS	NS	NS	NS	NS	NS

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

followed by cultivator tillage twice (T_4) either at 30 DAS or at harvest. Highest density was registered by minimum tillage (T_5) at all the growth stages, which was on par with mould board ploughing followed by cultivator tillage twice (T_3) at 60 DAS alone. The influence of T_3 and T_4 on other grasses was on par with each other at all the growth stages of observation.

Significant variation was observed among weed management methods in altering the density of other grasses in maize. Lowest density of other grasses was observed with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2). Unweeded control (W_4) recorded the highest density of other grasses at all the growth stages of observation. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were on par and were significantly superior to W_4 in reducing the density of other grasses at all the growth stages.

The interaction effect between preparatory tillage and weed management methods was not significant in altering the density of other grasses at all the growth stages of observation.

4.1.2.4. *Cyperus rotundus*

Sunflower

Cyperus rotundus population in sunflower was significantly influenced by preparatory tillage and weed management methods (Table 7). Either country plough tillage twice (T_1) or cultivator tillage twice (T_2) recorded the lowest density of *Cyperus rotundus* at 30 and 60 DAS. However, T_1 and T_2 were on par with minimum tillage (T_5) in reducing the density of *Cyperus rotundus* at harvest stage. Highest density of *Cyperus rotundus* was recorded by disc ploughing followed by cultivator tillage twice (T_4) which was on par with mould board ploughing followed by cultivator tillage twice (T_3) at 60 DAS and at harvest stages, but T_4 recorded higher density of *Cyperus rotundus* than in T_3 at 30 DAS.

Significant reduction in *Cyperus rotundus* population was observed with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) which resulted in the lowest density at all the growth stages. Highest density was registered with unweeded control (W_4) at all the growth stages. Hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40

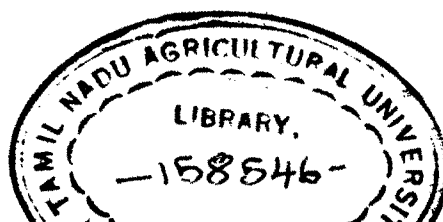


Table 7. Effect of preparatory tillage and weed management methods on density of *Cyperus rotundus* (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	3.68(15.35)	4.36(21.12)	4.63(23.69)	3.69(15.35)	4.35(20.96)	4.50(22.48)
T ₂	3.75(16.05)	4.57(23.53)	4.55(23.12)	3.52(14.24)	4.26(20.55)	4.32(20.73)
T ₃	3.83(16.52)	5.02(29.43)	5.12(29.93)	3.86(16.91)	5.06(30.29)	5.33(33.13)
T ₄	4.14(19.35)	5.11(29.40)	5.21(30.11)	4.01(18.21)	4.66(24.61)	4.75(25.60)
T ₅	3.93(17.70)	4.63(24.06)	4.74(24.79)	3.88(17.36)	4.59(23.68)	4.78(25.62)
SEd	0.05	0.09	0.09	0.05	0.09	0.11
CD (5%)	0.12	0.22	0.20	0.13	0.22	0.26
W ₁	3.84(16.20)	4.57(22.92)	4.52(22.49)	3.73(15.31)	4.38(21.11)	4.68(24.12)
W ₂	2.96(9.68)	3.64(14.58)	4.19(19.32)	2.82(8.73)	3.56(14.00)	3.95(17.30)
W ₃	3.79(15.78)	4.86(25.96)	4.94(26.83)	3.72(15.2)	4.52(22.49)	4.48(22.35)
W ₄	4.89(26.32)	5.89(38.57)	5.75(36.67)	4.90(26.41)	5.86(38.48)	5.83(38.27)
SEd	0.11	0.13	0.10	0.11	0.14	0.13
CD (5%)	0.22	0.27	0.20	0.24	0.29	0.27
<u>T at W</u> SEd	0.22	0.28	0.21	0.23	0.29	0.28
CD (5%)	NS	0.58	0.45	NS	0.61	0.60
<u>W at T</u> SEd	0.24	0.30	0.22	0.26	0.32	0.30
CD (5%)	NS	0.62	0.46	NS	0.66	0.62

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

DAS were proved to be better than W₄ and were significantly different from each other at 60 DAS and at harvest, but on par with each other at 30 DAS.

Interaction between preparatory tillage and weed management methods was significant in influencing the *Cyperus rotundus* density both at 60 DAS and at harvest (Table 21). Combination of pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS with cultivator tillage twice (T₂W₂) resulted in the lowest density of *Cyperus rotundus*. However, combination of herbicidal + manual weeding (W₂) with any other preparatory tillage methods (T₁W₂, T₃W₂, T₄W₂ and T₅W₂) was equally effective as that of T₂W₂ in reducing the density of *Cyperus rotundus* at 60 DAS, T₂W₂ was comparable with the combination of W₂ either with country plough tillage twice (T₁W₂) or with mould board ploughing followed by cultivator tillage twice (T₃W₂). Highest density was recorded by the combination of unweeded control with mould board ploughing followed by cultivator tillage (T₃W₄) both at 60 DAS and at harvest stages. Unweeded control either with disc plough followed by cultivator tillage (T₄W₄) or with minimum tillage (T₅W₄) resulted in higher densities of *Cyperus rotundus* at 60 DAS. Either country plough tillage or cultivator tillage in combination with hand weeding twice on 20 and 40 DAS (T₁W₁ or T₂W₁) or mechanical weeding twice on 20 and 40 DAS (T₁W₃ or T₂W₃) recorded lower density of *Cyperus rotundus* at 60 DAS and at harvest as against with unweeded control in combination with any other preparatory tillage methods.

Maize

Cyperus rotundus density was significantly influenced both by the preparatory tillage and weed management methods (Table 7). Cultivator tillage twice (T₂) registered the lowest density at all the growth stages, but was comparable with that of country plough tillage twice (T₁) at 60 DAS and at harvest. Highest density was recorded by disc ploughing followed by cultivator tillage twice (T₄), however it was on par with minimum tillage (T₅) at 30 DAS. Whereas, mould board ploughing followed by cultivator tillage twice (T₃) recorded the highest density of *Cyperus rotundus* at 60 DAS as well as at harvest. Both T₄ and T₅ were on par and significantly superior to T₃ at 60 DAS and at harvest in reducing the density of *Cyperus*

rotundus, while the effect of minimum tillage (T_5) on the density of *Cyperus rotundus* was comparable with that of T_3 at 30 DAS in maize.

Significant variation in *Cyperus rotundus* density was observed with different weed management methods. Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) registered the lowest density, while unweeded control (W_4) recorded the highest density at all the growth stages. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) were found to be on par, but significantly superior to W_2 in reducing the density of *Cyperus rotundus* at all the growth stages of observation.

Significant interaction effect between preparatory tillage and weed management methods was observed in altering the population of *Cyperus rotundus* at 60 DAS and at harvest (Table 24). Lowest density of *Cyperus rotundus* was recorded by the combination of pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding and cultivator tillage twice (T_2W_2) and was comparable with that of the combination of herbicide + manual weeding either with country plough tillage twice (T_1W_2) or with mould board ploughing followed by cultivator tillage twice (T_3W_2) at 60 DAS. However, at harvest stage, combination of mechanical weeding twice with cultivator tillage (T_2W_3) recorded the lowest density of *Cyperus rotundus* which was on par with the combination of herbicide + manual weeding with country plough tillage (T_1W_2) or mould board ploughing + cultivator tillage (T_3W_2) or disc ploughing followed by cultivator tillage (T_4W_2) and with minimum tillage (T_5W_2). Unweeded control in combination with mould board ploughing followed by cultivator tillage twice (T_3W_4) resulted in the highest density of *Cyperus rotundus* both at 60 DAS and at harvest in maize.

4.1.2.5. *Parthenium hysterophorus*

Sunflower

Parthenium hysterophorus density was significantly affected both by preparatory tillage and weed management methods (Table 8). Lowest density was observed with disc ploughing followed by cultivator tillage twice (T_4). However, it was comparable with that of mould board ploughing followed by cultivator tillage twice (T_3) at all growth stages. Minimum tillage (T_5) recorded the highest density of *Parthenium hysterophorus* which was on par with that of

Table 8. Effect of preparatory tillage and weed management methods on density of *Parthenium hysterophorus* (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	3.12(11.66)	4.07(19.37)	4.22(20.97)	3.12(11.42)	3.89(17.45)	4.02(18.79)
T ₂	3.04(11.12)	4.05(19.14)	4.35(21.62)	3.13(11.55)	4.03(18.22)	3.93(17.84)
T ₃	2.29(6.05)	3.10(10.82)	3.26(12.06)	2.23(5.73)	3.06(10.44)	3.19(11.32)
T ₄	2.18(5.44)	2.94(9.72)	3.02(10.31)	2.10(5.06)	2.88(9.20)	3.00(10.01)
T ₅	3.20(12.38)	4.19(20.60)	4.21(20.72)	3.27(12.89)	4.01(18.37)	4.28(21.09)
SEd	0.15	0.18	0.19	0.17	0.17	0.17
CD (5%)	0.34	0.42	0.43	0.39	0.39	0.39
W ₁	2.95(9.83)	3.97(17.79)	3.98(17.85)	2.93(9.78)	3.74(15.73)	3.83(16.51)
W ₂	1.51(2.52)	2.35(6.08)	2.51(6.96)	1.65(3.00)	2.65(7.75)	2.60(7.44)
W ₃	2.99(10.11)	3.78(16.06)	3.90(17.13)	2.87(9.41)	3.59(14.19)	3.76(15.85)
W ₄	3.62(14.86)	4.59(23.79)	4.86(26.60)	3.64(15.13)	4.32(20.97)	4.55(23.44)
SEd	0.12	0.13	0.14	0.11	0.10	0.12
CD (5%)	0.26	0.28	0.28	0.24	0.20	0.24
<u>T at W</u> SEd	0.29	0.32	0.33	0.28	0.26	0.29
CD (5%)	0.61	0.68	0.70	0.61	0.56	0.61
<u>W at T</u> SEd	0.28	0.30	0.31	0.26	0.22	0.27
CD (5%)	0.58	0.62	0.63	0.54	0.46	0.55

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

country plough tillage twice (T₁) or cultivator tillage twice (T₂) at all the growth stages of observation.

Among the weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (W₂) registered the lowest density, whereas, unweeded control (W₄) recorded the highest density of *Parthenium hysterophorus* throughout the crop growth. Both hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS were observed to be significantly superior to W₄ in reducing the density of *Parthenium hysterophorus* but were on par with each other at all the growth stages of observation.

The interaction effect between preparatory tillage and weed management methods was significant in changing the population of *Parthenium hysterophorus* (Table 9). Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.5 kg/ha followed by hand weeding on 40 DAS in combination with disc ploughing followed by cultivator tillage twice (T₄W₂) registered the lowest density which was on par with that of herbicidal + manual weeding in combination with any other tillage methods (T₁W₂, T₂W₂, T₃W₂ and T₅W₂) both 30 and 60 DAS. However, T₄W₂ was comparable with combination of herbicidal + manual weeding with country plough tillage twice (T₁W₂), mould board tillage followed by cultivator tillage twice (T₃W₂) and with minimum tillage (T₅W₂) at harvest stage. Highest density of *Parthenium hysterophorus* was recorded by unweeded control in combination with minimum tillage (T₅W₄) and found to be on par with unweeded control in combination with either country plough tillage (T₁W₄) or cultivator tillage (T₂W₄) at all the growth stages.

Maize

Significant influence on the density of *Parthenium hysterophorus* was observed with the preparatory tillage and weed management methods (Table 8). Disc ploughing followed by cultivator tillage twice (T₄) recorded the lowest density of *Parthenium hysterophorus* which was on par with that of mould board ploughing followed by cultivator tillage twice (T₃) at all the growth stages. Highest density of *Parthenium hysterophorus* was observed with minimum

Table 9. Interaction effect of preparatory tillage and weed management methods on density of *Parthenium hysterophorus* (No./m²) in sunflower

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	3.35 (12.35)	1.55 (2.64)	3.46 (13.17)	4.10 (18.48)	3.12 (11.66)	4.49 (22.12)	2.38 (6.24)	4.24 (19.76)	5.18 (29.38)	4.07 (19.37)	4.50 (22.23)	2.38 (6.25)	4.52 (22.36)	5.49 (33.06)	4.22 (20.97)
T ₂	3.30 (11.95)	1.52 (2.54)	3.27 (11.75)	4.08 (18.26)	3.04 (11.12)	4.49 (22.10)	2.36 (6.11)	4.22 (19.50)	5.13 (28.86)	4.05 (19.14)	4.45 (21.75)	2.95 (9.54)	4.49 (22.13)	5.49 (33.07)	4.35 (21.62)
T ₃	2.39 (6.26)	1.50 (2.48)	2.41 (6.37)	2.88 (9.12)	2.29 (6.05)	3.26 (11.70)	2.33 (5.98)	3.12 (10.66)	3.69 (14.95)	3.10 (10.82)	3.29 (11.88)	2.39 (6.27)	3.32 (12.08)	4.06 (18.04)	3.26 (12.06)
T ₄	2.26 (5.61)	1.46 (2.34)	2.26 (5.62)	2.73 (8.19)	2.18 (5.44)	3.08 (10.41)	2.26 (5.59)	2.92 (9.36)	3.51 (13.52)	2.94 (9.72)	3.11 (10.63)	2.29 (5.75)	2.95 (9.57)	3.73 (15.29)	3.02 (10.31)
T ₅	3.44 (13.02)	1.54 (2.60)	3.53 (13.65)	4.30 (20.28)	3.20 (12.38)	4.54 (22.62)	2.43 (6.50)	4.38 (21.06)	5.42 (32.24)	4.19 (20.60)	4.56 (22.77)	2.53 (7.02)	4.22 (19.52)	5.53 (33.58)	4.21 (20.72)
Mean	2.95 (9.83)	1.51 (2.52)	2.99 (10.11)	3.62 (14.86)	2.77 (9.33)	3.97 (17.79)	2.35 (6.08)	3.78(1 6.06)	4.59 (23.79)	3.67 (15.93)	3.98 (17.85)	2.51 (6.96)	3.90 (17.13)	4.86 (26.60)	3.81 (17.13)
SEd	0.15	0.12	0.29	0.28	0.28	0.18	0.13	0.32	0.30	0.30	0.19	0.14	0.33	0.31	0.31
CD (5%)	0.34	0.26	0.61	0.58	0.58	0.42	0.28	0.68	0.62	0.62	0.43	0.28	0.70	0.63	0.63

Figures in parenthesis are original values
T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

tillage (T₅) and was comparable with that of either country plough tillage twice (T₁) or cultivator tillage twice (T₂) at 30 and 60 DAS as well as at harvest.

Among the weed management methods, pre-emergence application of atrazine 0.25 kg/ha (W₂) was found to be superior in reducing the density of *Parthenium hysterophorus* and resulted in the lowest density of *Parthenium hysterophorus*, while unweeded control (W₄) recorded the highest density at all the growth stages. Both hand weeding twice (W₁) and mechanical weeding twice (W₃) at 20 and 40 DAS were proved to be superior to W₄ and both were on par with each other at all the growth stages of observation.

Significant interaction effect was found between the preparatory tillage and weed management methods (Table 10). Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS combined with disc ploughing followed by cultivator tillage twice (T₄W₂) resulted in the lowest density of *Parthenium hysterophorus*, which was comparable with that of herbicidal + manual weeding in combination with any other tillage methods (T₁W₂, T₂W₂, T₃W₂ and T₅W₂) at 30 DAS. The density of *Parthenium hysterophorus* with T₄W₂ was comparable with that of disc ploughing followed by cultivator tillage in combination with either manual weeding twice (T₄W₁) or mechanical weeding twice (T₄W₃) at 60 DAS. At harvest, W₂ combined with cultivator tillage twice (T₂W₂) recorded the lowest density and was on par with T₁W₂, T₃W₂, T₄W₂, T₅W₂ and T₄W₃. Highest density of *Parthenium hysterophorus* was registered by the combination of unweeded control with minimum tillage (T₅W₄) at all the three stages and was comparable with the combination of unweeded control with either country plough tillage twice (T₁W₄) or cultivator tillage twice (T₂W₄) at 30 DAS, mechanical weeding twice combined with country plough tillage (T₁W₃) and unweeded control with mould board ploughing followed by cultivator tillage (T₃T₄) at 60 DAS. At harvest stage, unweeded control in combination with either minimum tillage (T₅W₄) or country plough tillage (T₁W₄) recorded the highest density of *Parthenium hysterophorus*.

Table 10. Interaction effect of preparatory tillage and weed management methods on density of *Parthenium hysterophorus* (No./m²) in maize

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	3.33 (12.00)	1.84 (3.72)	3.27 (11.74)	4.06 (18.04)	3.12 (11.42)	4.15 (18.89)	2.51 (6.91)	4.01 (17.63)	4.91 (26.40)	3.89 (17.45)	4.18 (19.18)	2.51 (6.90)	4.22 (19.55)	5.19 (29.53)	4.02 (18.79)
T ₂	3.31 (12.04)	1.76 (3.42)	3.23 (11.45)	4.20 (19.32)	3.13 (11.55)	4.18 (19.17)	3.00 (9.86)	4.15 (18.89)	4.77 (24.98)	4.03 (18.22)	4.18 (19.20)	2.40 (6.33)	4.24 (19.71)	4.88 (26.14)	3.93 (17.84)
T ₃	2.32 (5.90)	1.54 (2.60)	2.21 (5.39)	2.87 (9.04)	2.23 (5.73)	3.10 (10.52)	2.57 (7.24)	3.00 (9.87)	3.59 (14.14)	3.06 (10.44)	3.27 (11.77)	2.62 (7.54)	3.15 (10.92)	3.70 (15.05)	3.19 (11.32)
T ₄	2.19 (5.25)	1.44 (2.28)	2.16 (5.13)	2.63 (7.58)	2.10 (5.06)	2.92 (9.34)	2.45 (6.62)	2.79 (8.52)	3.35 (12.32)	2.88 (9.20)	3.00 (9.88)	2.58 (7.32)	2.94 (9.47)	3.49 (13.38)	3.00 (10.01)
T ₅	3.51 (13.54)	1.65 (3.00)	3.49 (13.34)	4.45 (21.71)	3.27 (12.89)	4.35 (20.70)	2.72 (8.12)	4.00 (17.58)	4.97 (27.05)	4.01 (18.37)	4.53 (22.53)	2.88 (9.11)	4.23 (19.61)	5.50 (33.12)	4.28 (21.09)
Mean	2.93 (9.78)	1.65 (3.00)	2.87 (9.41)	3.64 (15.13)	2.77 (9.33)	3.74 (15.73)	2.65 (7.75)	3.59 (14.49)	4.32 (20.97)	3.57 (14.74)	3.83 (16.57)	2.60 (7.44)	3.76 (15.85)	4.55 (23.44)	3.68 (15.81)
SEd	0.17	0.11	0.28		0.26	0.17	0.10	0.26		0.22	0.17	0.12	0.29		0.27
CD (5%)	0.39	0.24	0.61		0.54	0.39	0.20	0.50		0.46	0.39	0.24	0.61		0.55

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

4.1.2.6. *Trianthema portulacastrum*

Sunflower

Both preparatory tillage and weed management methods were found to be significant in influencing the density of *Trianthema portulacastrum* (Table 11). Either disc ploughing (T₄) or mould board ploughing (T₃) followed by cultivator tillage twice recorded the lowest density and minimum tillage (T₅) registered the highest density of *Trianthema portulacastrum* which was on par with country plough tillage twice (T₁) and cultivator tillage twice (T₂) at all the three stages.

In case of weed management methods, lowest density of *Trianthema portulacastrum* was observed with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂). Whereas, unweeded control (W₄) recorded the highest density of *Trianthema portulacastrum* at all the three growth stages. Both hand weeding twice (W₁) and mechanical weeding twice (W₃) at 20 and 40 DAS were found to be significantly superior to unweeded control (W₄) and were comparable with each other at all the growth stages.

Significant interaction effect was observed between preparatory tillage and weed management methods at all the growth stages (Table 12). Combination of pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂) with disc ploughing followed by cultivator tillage twice (T₄W₂) recorded the lowest density of *Trianthema portulacastrum* which was comparable with that of the combination of W₂ with any other tillage methods (T₁W₂, T₂W₂, T₃W₂ and T₅W₂) both at 30 and 60 DAS. Whereas, at harvest, T₄W₂ was on par with the combination of W₂ with country plough tillage twice (T₁W₂), mould board tillage and disc ploughing followed by cultivator tillage twice (T₃W₂ and T₄W₂) and with minimum tillage (T₅W₂). At all growth stages, unweeded control combined with minimum tillage (T₅W₄) registered the highest density of *Trianthema portulacastrum*. However, the density with T₅W₄ was comparable with the combination of unweeded control with country plough tillage (T₁W₄) or cultivator tillage (T₂W₄) at all the growth stages of observation.

Table 11. Effect of preparatory tillage and weed management methods on density of *Trianthema portulacastrum* (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	4.57(25.06)	5.98(41.72)	6.20(45.18)	4.12(19.81)	5.13(30.26)	5.30(19.81)
T ₂	4.45(23.70)	5.94(41.23)	6.38(46.57)	4.12(20.03)	5.30(31.59)	5.17(20.03)
T ₃	3.37(13.02)	4.55(23.31)	4.79(25.99)	2.94(9.93)	4.03(18.10)	4.44(9.93)
T ₄	3.19(11.62)	4.32(20.93)	4.44(22.20)	2.77(8.77)	3.79(15.95)	3.95(8.77)
T ₅	4.70(26.70)	6.16(44.38)	6.18(44.63)	4.31(22.36)	5.28(31.85)	5.64(22.36)
SEd	0.22	0.27	0.27	0.22	0.22	0.21
CD (5%)	0.50	0.62	0.64	0.52	0.51	0.48
W ₁	4.33(21.16)	5.83(38.30)	5.85(38.45)	3.86(16.96)	4.92(27.28)	5.24(16.96)
W ₂	2.21(5.39)	3.45(13.10)	3.68(15.01)	2.17(5.20)	3.49(13.43)	3.42(5.20)
W ₃	4.37(21.67)	5.54(34.60)	5.73(36.90)	3.78(16.31)	4.73(25.13)	4.95(16.31)
W ₄	5.31(31.91)	6.73(51.24)	7.14(57.31)	4.79(26.24)	5.69(36.36)	6.00(26.24)
SEd	0.18	0.20	0.20	0.15	0.13	0.16
CD (5%)	0.38	0.41	0.41	0.32	0.27	0.33
<u>T at W</u> SEd	0.42	0.47	0.48	0.37	0.34	0.37
CD (5%)	0.90	1.01	1.03	0.80	0.74	0.80
<u>W at T</u> SEd	0.42	0.45	0.45	0.35	0.30	0.36
CD (5%)	0.86	0.92	0.93	0.71	0.61	0.74

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Table 12. Interaction effect of preparatory tillage and weed management methods on density of *Trianthema portulacastrum* (No./m²) in sunflower

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	4.93 (26.60)	2.26 (5.62)	5.08 (28.28)	6.02 (39.76)	4.57 (25.06)	6.59 (47.6)	3.50 (13.40)	6.23 (42.56)	7.60 (63.28)	5.98 (41.72)	6.61 (47.88)	3.50 (13.47)	6.63 (48.16)	8.06 (71.22)	6.20 (45.18)
T ₂	4.83 (25.62)	2.20 (5.32)	4.79 (25.20)	5.96 (38.92)	4.45 (23.76)	6.59 (47.6)	3.46 (13.16)	6.19 (42.00)	7.53 (62.16)	5.94 (41.23)	6.54 (46.84)	4.33 (20.55)	6.60 (47.67)	8.06 (71.23)	6.38 (46.57)
T ₃	3.50 (13.44)	2.21 (5.36)	3.53 (13.71)	4.23 (19.60)	3.37 (13.02)	4.76 (25.2)	3.43 (12.88)	4.58 (22.96)	5.42 (32.20)	4.55 (23.31)	4.83 (25.59)	3.51 (13.52)	4.87 (26.03)	5.95 (38.85)	4.79 (25.99)
T ₄	3.31 (12.05)	2.15 (5.06)	3.27 (11.75)	4.01 (17.64)	3.19 (11.62)	4.52 (22.40)	3.31 (12.04)	4.29 (20.16)	5.15 (29.12)	4.32 (20.93)	4.57 (22.90)	3.36 (12.39)	4.33 (20.61)	5.48 (32.93)	4.44 (22.20)
T ₅	5.06 (28.12)	2.26 (5.61)	5.18 (29.42)	6.37 (43.67)	4.70 (26.70)	6.67 (48.72)	3.57 (14.01)	6.43 (45.36)	7.96 (69.44)	6.16 (44.38)	6.69 (49.05)	3.71 (15.12)	6.19 (42.05)	8.13 (72.33)	6.18 (44.63)
Mean	4.33 (21.16)	2.21 (5.39)	4.37 (21.67)	5.31 (31.91)	4.06 (20.03)	5.83 (38.30)	3.45 (13.10)	5.54 (34.60)	6.73 (51.24)	5.39 (34.3)	5.85 (38.45)	3.68 (15.01)	5.73 (36.90)	7.14 (57.31)	5.60 (36.91)
	T	W	T at W	W at T	W at T	T	W	T at W	W at T	W at T	T	W	T at W	W at T	W at T
SEd	0.22	0.18	0.42	0.42	0.42	0.27	0.20	0.47	0.45	0.45	0.27	0.20	0.48	0.45	0.45
CD (5%)	0.50	0.38	0.90	0.86	0.86	0.62	0.41	1.01	0.92	0.92	0.64	0.41	1.03	0.93	0.93

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

Maize

The density of *Trianthema portulacastrum* in maize was affected both by preparatory tillage and weed management methods (Table 11). Lowest density was registered by either disc ploughing (T₄) or mould board ploughing (T₃) followed by cultivator tillage twice and the highest density of *Trianthema portulacastrum* was recorded with minimum tillage (T₅) which was comparable with that of country plough tillage twice (T₁) and cultivator tillage twice (T₂) at all the three growth stages.

Among weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W₂) resulted in the lowest density of *Trianthema portulacastrum* and unweeded control (W₄) recorded the highest density of *Trianthema portulacastrum* at all the growth stages. Either hand weeding twice (W₁) or mechanical weeding twice (W₃) on 20 and 40 DAS was significantly superior to unweeded control (W₄) in reducing the density of *Trianthema portulacastrum* and were on par with each other at all the growth stages.

Interaction between the preparatory tillage and weed management methods was found to be significant in influencing the density of *Trianthema portulacastrum* (Table 13). Combination of pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS with disc ploughing followed by cultivator tillage twice (T₄W₂) registered the lowest density at 30 DAS as well as at 60 DAS, while the combination of herbicidal + manual weeding with cultivator tillage twice (T₂W₂) recorded the lowest density at harvest. Comparable density of *Trianthema portulacastrum* was observed in T₄W₂ that of all the preparatory tillage treatments in combination with W₂ (T₁W₂, T₂W₂, T₃W₂, T₅W₂) at 30 DAS, with country plough tillage twice (T₁W₂), minimum tillage (T₅W₂) and combination of disc ploughing followed by cultivator tillage twice with hand weeding twice (T₄W₁), or mechanical weeding twice (T₄W₃) at 60 DAS. At harvest stage, *Trianthema portulacastrum* density in T₂W₂ was on par with the combination of herbicidal + manual weeding with any other preparatory tillage methods (T₁W₂, T₃W₂, T₄W₂, T₅W₂) and disc ploughing followed by cultivator tillage twice combined with mechanical weeding twice (T₄W₃). Highest density of *Trianthema portulacastrum* was observed by the minimum tillage combined with unweeded

Table 13. Interaction effect of preparatory tillage and weed management methods on density of *Trianthema portulacastrum* (No./m²) in maize

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	4.39 (21.15)	2.42 (6.45)	4.31 (20.36)	5.34 (31.28)	4.12 (19.81)	5.47 (32.75)	3.31 (11.99)	5.28 (30.56)	6.46 (45.76)	5.13 (30.26)	5.51 (21.15)	3.30 (6.45)	5.56 (20.36)	6.83 (31.28)	5.30 (19.81)
T ₂	4.36 (20.88)	2.32 (5.92)	4.25 (19.84)	5.53 (33.50)	4.12 (20.03)	5.51 (33.23)	3.95 (17.10)	5.47 (32.75)	6.29 (43.30)	5.30 (31.59)	5.51 (20.88)	3.16 (5.92)	5.58 (19.84)	6.43 (33.50)	5.17 (20.03)
T ₃	3.05 (10.22)	2.03 (4.51)	2.92 (9.34)	3.78 (15.68)	2.94 (9.93)	4.08 (18.23)	3.38 (12.56)	3.95 (17.11)	4.73 (24.52)	4.03 (18.10)	5.27 (10.22)	3.45 (4.51)	4.95 (9.34)	4.88 (15.68)	4.44 (9.93)
T ₄	2.88 (9.10)	1.90 (3.95)	2.85 (8.90)	3.46 (13.15)	2.77 (8.77)	3.84 (16.20)	3.23 (11.47)	3.67 (14.77)	4.41 (21.36)	3.79 (15.95)	3.95 (9.10)	3.40 (3.95)	3.87 (8.9)	4.60 (13.15)	3.95 (8.77)
T ₅	4.63 (23.48)	2.18 (5.21)	4.59 (23.13)	5.86 (37.63)	4.31 (22.36)	5.73 (35.99)	3.58 (14.07)	5.27 (30.48)	6.54 (46.88)	5.28 (31.85)	5.97 (23.48)	3.79 (5.21)	5.57 (23.13)	7.24 (37.63)	5.64 (22.36)
Mean	3.86 (16.96)	2.17 (5.20)	3.78 (16.31)	4.79 (26.24)	3.65 (16.18)	4.92 (27.28)	3.49 (13.43)	4.73 (25.13)	5.69 (36.36)	4.71 (25.55)	5.24 (16.96)	3.42 (5.20)	4.95 (16.31)	6.00 (26.24)	4.90 (16.18)
SEd	T	W	T at W	W at T	T	W	T at W	W at T	T	W	T at W	W at T	T	W	T at W
	0.22	0.15	0.37	0.35	0.22	0.13	0.34	0.30	0.21	0.10	0.37	0.36	0.21	0.10	0.37
CD (5%)	0.51	0.32	0.80	0.71	0.51	0.27	0.74	0.61	0.48	0.33	0.80	0.74	0.48	0.33	0.80

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

control (T_5W_4) which was similar to the combination of unweeded control either with country plough tillage twice (T_1W_4) or cultivator tillage twice (T_2W_4) both at 30 and 60 DAS. Whereas, the density of T_5W_4 was on par with that of T_1W_4 alone at harvest stage.

4.1.2.7. *Digera arvensis*

Sunflower

Preparatory tillage and weed management methods significantly affected the density of *Digera arvensis* (Table 14). Among the tillage methods, the lowest density was recorded by either mould board ploughing (T_3) or disc ploughing (T_4) followed by cultivator tillage twice at all the growth stages. Minimum tillage (T_5) resulted in the highest density, which was comparable with that of country plough tillage twice (T_1) or cultivator tillage twice (T_2) at all the growth stages of observation.

In case of weed management methods, the lowest density of *Digera arvensis* was registered with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2). Whereas, unweeded control (W_4) recorded the highest density of *Digera arvensis* at all the growth stages. Hand weeding twice (W_1) or mechanical weeding twice (T_3) on 20 and 40 DAS was found to be superior to unweeded control (W_4) in recording lower density of *Digera arvensis* but was on par with each other at all the growth stages.

Significant interaction effect was noticed between preparatory tillage and weed management methods in affecting the density of *Digera arvensis* at all the growth stages (Table 15). Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS in combination with disc ploughing followed by cultivator tillage twice (T_4W_2) recorded the lowest density of *Digera arvensis*. However, the density with T_4W_2 was comparable with that of all other preparatory tillage methods in combination with W_2 (T_1W_2 , T_2W_2 , T_3W_2 and T_5W_2) at all the growth stages. Highest density of *Digera arvensis* was recorded with unweeded control in combination with minimum tillage (T_5W_4) which was on par with that of the combination of unweeded control either with country plough tillage twice (T_1W_4) or cultivator tillage twice (T_2W_4) at all the growth stages.

Table 14. Effect of preparatory tillage and weed management methods on density of *Digera arvensis* (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	3.77(17.01)	4.93(28.31)	5.11(30.65)	3.52(14.47)	4.38(22.11)	4.53(23.80)
T ₂	3.67(16.15)	4.90(27.97)	5.26(31.60)	3.52(14.64)	4.53(23.08)	4.47(23.09)
T ₃	2.77(8.84)	3.75(15.81)	3.95(17.63)	2.52(7.26)	3.45(13.22)	3.59(14.34)
T ₄	2.62(7.88)	3.56(14.20)	3.65(15.06)	2.37(6.41)	3.24(11.65)	3.38(12.68)
T ₅	3.87(18.11)	5.07(30.10)	5.09(30.28)	3.69(16.33)	4.51(23.27)	4.82(26.72)
SEd	0.18	0.22	0.23	0.19	0.19	0.19
CD (5%)	0.42	0.51	0.53	0.44	0.44	0.44
W ₁	3.56(14.37)	4.80(25.98)	4.82(26.09)	3.30(12.39)	4.21(19.93)	4.32(20.91)
W ₂	1.83(3.66)	2.84(8.89)	3.03(10.18)	1.85(3.80)	2.98(9.81)	4.92(9.42)
W ₃	3.60(14.71)	4.57(23.48)	4.72(25.04)	3.23(11.91)	4.04(18.36)	4.26(20.46)
W ₄	4.37(21.66)	5.55(34.77)	5.88(38.88)	4.10(19.18)	4.86(26.57)	5.13(29.70)
SEd	0.15	0.16	0.16	0.13	0.11	0.13
CD (5%)	0.31	0.33	0.34	0.27	0.23	0.27
<u>T at W</u> SEd	0.35	0.39	0.40	0.32	0.29	0.32
CD (5%)	0.74	0.83	0.85	0.69	0.63	0.70
<u>W at T</u> SEd	0.34	0.37	0.37	0.30	0.25	0.30
CD (5%)	0.70	0.75	0.77	0.61	0.52	0.62

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Table 15. Interaction effect of preparatory tillage and weed management methods on density of *Digera arvensis* (No./m²) in sunflower

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	4.06 (18.08)	1.87 (3.84)	4.18 (19.20)	4.96 (26.94)	3.77 (17.01)	5.43 (32.30)	2.88 (9.12)	5.13 (28.88)	6.26 (42.94)	4.93 (28.31)	5.44 (32.49)	2.89 (9.14)	5.46 (32.68)	6.64 (48.32)	5.11 (30.65)
T ₂	3.99 (17.46)	1.82 (3.63)	3.95 (17.11)	4.91 (26.41)	3.67 (16.15)	5.43 (32.30)	2.85 (8.93)	5.10 (28.50)	6.20 (42.18)	4.90 (27.97)	5.38 (31.78)	3.56 (13.94)	5.43 (32.35)	6.64 (48.33)	5.26 (31.60)
T ₃	2.88 (9.13)	1.81 (3.62)	2.91 (9.31)	3.48 (13.32)	2.77 (8.84)	3.95 (17.10)	2.82 (8.74)	3.77 (15.58)	4.46 (21.85)	3.75 (15.81)	3.98 (17.36)	2.89 (9.17)	4.01 (17.66)	4.90 (22.36)	3.95 (17.63)
T ₄	2.73 (8.17)	1.76 (3.42)	2.70 (7.98)	3.30 (11.98)	2.62 (7.88)	3.72 (15.20)	2.73 (8.17)	3.53 (13.68)	4.24 (19.76)	3.56 (14.20)	3.76 (15.54)	2.77 (8.40)	3.57 (13.99)	4.51 (22.34)	3.65 (15.06)
T ₅	4.16 (19.01)	1.86 (3.82)	4.27 (19.96)	5.20 (29.67)	3.87 (18.11)	5.49 (33.03)	2.94 (9.50)	5.30 (30.78)	6.56 (47.12)	5.07 (30.10)	5.51 (33.28)	3.06 (10.26)	5.10 (28.53)	6.69 (49.08)	5.09 (30.28)
Mean	3.56 (14.37)	1.83 (3.66)	3.60 (14.71)	4.37 (21.66)	3.34 (13.60)	4.80 (25.98)	2.84 (8.89)	4.57 (23.48)	5.55 (34.77)	4.44 (23.27)	4.82 (26.09)	3.03 (10.18)	4.72 (25.04)	5.88 (38.88)	4.61 (25.05)
SEd	0.18	0.15	0.35		0.34	0.22	0.16	0.39		0.37	0.23	0.16	0.40		0.37
CD (5%)	0.42	0.31	0.74		0.70	0.51	0.33	0.83		0.75	0.53	0.34	0.35		0.77

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

The density of *Digera arvensis* was significantly influenced both by preparatory tillage and weed management methods (Table 14). Either disc ploughing (T₄) or mould board ploughing (T₃) followed by cultivator tillage twice recorded the lowest density at all the growth stages. Minimum tillage (T₅) registered the highest density of *Digera arvensis*, which was on par with that of both country plough tillage twice (T₁) and cultivator tillage twice (T₂) at 30 and 60 DAS as well as at harvest.

Among weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W₂) resulted in the lowest density of *Digera arvensis* and the highest density was registered by unweeded control (W₄) at all the growth stages. Either hand weeding twice (W₁) or mechanical weeding twice (W₃) on 20 and 40 DAS was superior to W₄ and were on par with each other.

Significant interaction effect was observed between preparatory tillage and weed management methods in influencing the density of *Digera arvensis* at all the growth stages (Table 16). Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W₂) combined with disc ploughing followed by cultivator tillage twice (T₄W₂) recorded the lowest density which was on par with the combination of any other tillage method with herbicidal + manual weeding (T₁W₂, T₂W₂, T₃W₂ and T₅W₂) at 30 DAS. Comparable density of *Digera arvensis* was recorded among the country plough tillage twice (T₁W₂), minimum tillage (T₅W₂), mould board ploughing followed by cultivator tillage twice in combination with herbicide + hand weeding (T₃W₂) at 60 DAS. Either hand weeding twice (T₄W₁) or mechanical weeding twice combined with disc ploughing followed by cultivator tillage twice (T₄W₃) recorded comparable density of *Digera arvensis* at 60 DAS. At harvest stage, W₂ combined with cultivator tillage twice (T₂W₂) registered the lowest density which was on par with the combination of W₂ with any other tillage method (T₁W₂, T₃W₂, T₄W₂ and T₅W₂) and mechanical weeding twice combined with disc ploughing + cultivator tillage twice (T₄W₃). Highest density was recorded by the minimum tillage in association with unweeded control (T₅W₄) which was similar to that of both country plough tillage and cultivator tillage twice in combination with herbicide + hand weeding (T₁W₂ and T₂W₂) at 30 and 60 DAS.

Table 16. Interaction effect of preparatory tillage and weed management methods on density of *Digera arvensis* (No./m²) in maize

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	3.78 (15.46)	2.07 (4.71)	3.68 (14.81)	4.57 (22.86)	3.52 (14.47)	4.67 (23.93)	2.82 (8.76)	4.51 (22.33)	5.52 (33.44)	4.38 (22.11)	4.71 (24.29)	2.82 (8.74)	4.75 (24.76)	5.84 (37.41)	4.53 (23.80)
T ₂	3.73 (15.25)	1.98 (4.33)	3.64 (14.50)	4.72 (24.48)	3.52 (14.64)	4.71 (24.28)	3.37 (12.49)	4.67 (23.93)	5.37 (31.64)	4.53 (23.08)	4.71 (24.32)	2.70 (8.01)	4.96 (26.92)	5.50 (33.11)	4.47 (23.09)
T ₃	2.61 (7.47)	1.73 (3.30)	2.49 (6.82)	3.23 (11.46)	2.52 (7.26)	3.48 (13.32)	2.89 (9.18)	3.37 (12.50)	4.04 (17.91)	3.45 (13.22)	3.69 (14.91)	2.95 (9.55)	3.55 (13.83)	4.17 (19.07)	3.59 (14.34)
T ₄	2.46 (6.65)	1.62 (2.88)	2.43 (6.50)	2.96 (9.61)	2.37 (6.41)	3.28 (11.83)	2.76 (8.38)	3.14 (10.79)	3.77 (15.61)	3.24 (11.65)	3.38 (12.52)	2.91 (9.29)	3.31 (11.99)	3.93 (16.95)	3.38 (12.68)
T ₅	3.95 (17.15)	1.86 (3.80)	3.93 (16.90)	5.01 (27.50)	3.69 (16.33)	4.90 (26.30)	3.06 (10.28)	4.51 (22.27)	3.59 (34.26)	4.51 (23.27)	5.10 (28.53)	3.24 (11.55)	4.76 (24.84)	6.19 (41.96)	4.82 (26.72)
Mean	3.30 (12.39)	1.85 (3.80)	3.23 (11.91)	4.10 (19.18)	3.12 (11.82)	4.21 (19.93)	2.98 (9.81)	4.04 (18.36)	4.86 (26.57)	4.02 (18.67)	4.32 (20.91)	2.92 (9.42)	4.26 (20.46)	5.13 (29.70)	4.18 (20.12)
SEd	0.19	0.13	0.32	0.30	0.30	0.19	0.11	0.29	0.25	0.19	0.19	0.13	0.32	0.30	0.30
CD (5%)	0.44	0.27	0.69	0.61	0.61	0.44	0.23	0.63	0.52	0.44	0.44	0.27	0.70	0.62	0.62

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

Whereas, the density of *Digera arvensis* with T₅W₄ was comparable with that of the combination of T₁W₄ alone at harvest stage.

4.1.2.8. Other broad-leaved weeds

Sunflower

Density of other broad-leaved weeds was significantly influenced by preparatory tillage and weed management methods (Table 17). Lowest density was registered with disc ploughing followed by cultivator tillage twice (T₄) at all the three stages. However, T₄ was on par with mould board ploughing followed by cultivator tillage twice (T₃) both at 30 DAS and at harvest. Significant variation was observed between T₄ and T₃ at 60 DAS. Highest density was recorded by minimum tillage (T₅), which was similar to that of country plough tillage twice (T₁) and cultivator tillage twice (T₂) at all growth stages.

In case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂) resulted in the lowest density of other broad-leaved weeds while unweeded control (W₄) registered the highest density at all the three stages. Both hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS were significantly superior to unweeded control (W₄) and W₁ and W₃ both were comparable with each other at all the growth stages.

Significant interaction effect was observed between preparatory tillage and weed management methods at all the growth stages (Table 18). The density of other broad leaved weeds was the lowest in the treatment combination of pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS with disc ploughing followed by cultivator tillage twice (T₄W₂) at all the growth stages. However, T₄W₂ was comparable with herbicide + manual weeding combined with any other tillage methods (T₁W₂, T₂W₂, T₃W₂ and T₅W₂) at 30, 60 DAS and at harvest as well as with disc ploughing followed by cultivator tillage twice combined with mechanical weeding twice (T₄W₃) at 60 DAS alone. Highest density of other broad-leaved weeds was recorded with minimum tillage in association with unweeded control (T₅W₄) which was on par with either

Table 17. Effect of preparatory tillage and weed management methods on density of other broad-leaved weeds (No./m²) in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	5.48(36.00)	7.18(60.00)	7.32(63.04)	5.11(30.47)	5.35(33.31)	6.58(50.11)
T ₂	5.37(34.50)	7.14(59.42)	7.63(66.53)	5.11(30.82)	6.58(48.60)	6.42(47.59)
T ₃	4.06(18.90)	6.05(42.01)	5.73(37.14)	3.65(15.29)	5.01(27.85)	5.21(30.19)
T ₄	3.85(16.91)	5.21(30.38)	5.30(31.72)	3.44(13.50)	4.70(24.53)	4.82(25.71)
T ₅	5.65(38.36)	7.37(63.58)	7.39(63.77)	5.35(34.40)	6.55(49.00)	7.00(56.25)
SEd	0.26	0.28	0.32	0.27	0.26	0.28
CD (5%)	0.60	0.66	0.76	0.64	0.62	0.66
W ₁	5.21(30.65)	7.00(55.13)	6.92(53.73)	4.79(26.10)	6.11(41.96)	6.27(44.03)
W ₂	2.69(7.95)	4.19(19.26)	4.40(21.44)	2.69(8.01)	4.33(20.67)	4.25(19.84)
W ₃	5.25(31.22)	7.10(56.23)	6.84(52.72)	4.69(25.10)	5.86(38.66)	6.14(42.27)
W ₄	6.37(45.92)	8.08(73.70)	8.53(81.87)	5.95(40.38)	6.25(45.34)	7.37(61.73)
SEd	0.22	0.24	0.24	0.19	0.16	0.19
CD (5%)	0.45	0.50	0.50	0.39	0.33	0.40
<u>T at W</u> SEd	0.50	0.56	0.57	0.46	0.41	0.47
CD (5%)	1.07	1.18	1.22	1.00	0.89	1.09
<u>W at T</u> SEd	0.50	0.55	0.54	0.43	0.36	0.43
CD (5%)	1.02	1.14	1.11	0.89	0.74	0.89

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Table 18. Interaction effect of preparatory tillage and weed management methods on density of other broad-leaved weeds (No./m²) in sunflower

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	5.93 (38.55)	2.68 (7.91)	6.07 (40.37)	7.23 (57.20)	5.48 (36.00)	7.88 (68.01)	4.27 (20.02)	7.46 (61.01)	9.11 (90.99)	7.18 (60.00)	7.55 (62.40)	4.19 (19.25)	7.92 (68.80)	9.64 (101.74)	7.32 (63.04)
T ₂	5.84 (37.43)	2.70 (8.02)	5.79 (36.78)	7.14 (55.79)	5.37 (34.50)	7.92 (68.85)	4.23 (19.58)	7.40 (60.00)	9.03 (89.25)	7.14 (59.42)	7.82 (66.92)	5.17 (29.36)	7.88 (68.11)	9.64 (101.76)	7.63 (66.53)
T ₃	4.24 (19.68)	2.67 (7.85)	4.25 (19.82)	5.08 (28.27)	4.06 (18.90)	5.76 (36.31)	4.15 (18.86)	7.78 (66.35)	6.52 (46.55)	6.05 (42.01)	5.78 (36.56)	4.20 (19.32)	5.82 (37.18)	7.12 (55.50)	5.73 (37.14)
T ₄	3.98 (17.41)	2.64 (7.68)	3.93 (16.96)	4.83 (25.61)	3.85 (16.91)	5.43 (32.36)	4.03 (17.80)	5.14 (28.95)	6.22 (42.41)	5.21 (30.38)	5.46 (32.72)	4.02 (17.70)	5.08 (29.45)	6.55 (47.04)	5.30 (31.72)
T ₅	6.06 (40.20)	2.75 (8.33)	6.20 (42.18)	7.57 (62.76)	5.65 (38.36)	8.00 (70.13)	4.28 (20.06)	7.69 (64.84)	9.52 (99.30)	7.37 (63.58)	8.00 (70.08)	4.44 (21.60)	7.40 (60.08)	9.71 (103.33)	7.39 (63.77)
Mean	5.21 (30.65)	2.69 (7.95)	5.25 (31.22)	6.37 (45.92)	4.88 (28.93)	7.00 (55.13)	4.19 (19.26)	7.10 (56.23)	8.08 (73.70)	6.59 (51.08)	6.92 (53.73)	4.40 (21.44)	6.84 (52.72)	8.53 (81.87)	6.67 (52.44)
SED	0.26	0.22	0.50	0.50	0.50	0.28	0.24	0.56	0.55	0.55	0.32	0.24	0.57	0.54	0.54
CD (5%)	0.60	0.45	1.07	1.02	1.02	0.66	0.50	1.18	1.14	1.14	0.76	0.50	1.22	1.11	1.11

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

country plough tillage twice or cultivator tillage twice combined with unweeded control (T_1W_4 or T_2W_4) at all the growth stages.

Maize

Both preparatory tillage and weed management methods significantly influenced the density of other broad-leaved weeds (Table 17). Either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice registered the lowest density at all the growth stages. Highest density was recorded with minimum tillage (T_5), which was comparable with that of country plough tillage twice (T_1) and cultivator tillage twice (T_2) at 30 DAS and at harvest. But the density with T_5 was on par with that of T_2 alone at 60 DAS.

Among weed management methods, the lowest density of other broad leaved weeds was recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) while, unweeded control (W_4) registered the highest density at all the growth stages. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were on par with each other and significantly superior to unweeded control in controlling other broad leaved weeds.

Interaction effect between preparatory tillage and weed management methods was significant at all the stages of observation (Table 19). Lowest density was recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS combined with disc ploughing followed by cultivator tillage twice (T_4W_2) at 30 and 60 DAS and with the combination of W_2 with cultivator tillage twice (T_2W_2) at harvest. The lowest density of T_4W_2 was comparable with that of other tillage methods in combination with herbicidal + manual weeding (T_1W_2 , T_2W_2 , T_3W_2 and T_5W_2) at 30 DAS as well as with mechanical weeding twice combined with T_4 (T_4W_3) both at 60 DAS and at harvest stage.

Table 19. Interaction effect of preparatory tillage and weed management methods on density of other broad-leaved weeds (No./m²) in maize

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	5.45 (32.55)	3.01 (9.92)	5.35 (31.32)	6.63 (48.12)	5.11 (30.47)	6.78 (50.39)	4.10 (18.44)	6.55 (47.01)	3.98 (17.40)	5.35 (33.31)	6.83 (51.15)	4.10 (18.40)	6.90 (52.14)	8.48 (78.76)	6.58 (50.11)
T ₂	5.41 (32.12)	2.88 (9.12)	5.28 (30.53)	6.86 (51.54)	5.11 (30.82)	6.83 (51.13)	4.90 (26.13)	6.78 (50.38)	7.80 (66.61)	6.58 (48.60)	6.84 (51.20)	3.92 (16.88)	6.93 (52.56)	7.98 (69.72)	6.42 (47.59)
T ₃	3.79 (15.73)	2.52 (6.95)	3.62 (14.37)	4.69 (24.12)	3.65 (15.29)	5.06 (28.05)	4.20 (19.32)	4.90 (26.33)	5.87 (37.73)	5.01 (27.85)	5.35 (31.23)	4.28 (20.12)	5.15 (29.12)	6.05 (40.15)	5.21 (30.19)
T ₄	3.57 (14.00)	2.35 (6.08)	3.53 (13.69)	4.29 (20.23)	3.44 (13.50)	4.77 (24.92)	4.01 (17.65)	4.55 (22.72)	5.48 (32.86)	4.70 (24.53)	4.90 (26.36)	4.22 (19.53)	4.80 (25.26)	5.38 (31.69)	4.82 (25.71)
T ₅	3.74 (36.12)	2.70 (8.1)	5.70 (35.59)	7.27 (57.90)	3.35 (34.40)	7.11 (55.34)	4.44 (21.65)	6.54 (46.90)	8.11 (72.13)	6.55 (49.00)	7.40 (60.08)	4.71 (24.31)	6.91 (52.29)	8.98 (88.34)	7.00 (56.25)
Mean	4.79 (26.10)	2.69 (8.01)	4.69 (25.10)	5.95 (40.38)	4.53 (24.90)	6.11 (41.96)	4.33 (20.67)	5.86 (38.66)	6.25 (45.34)	5.64 (36.66)	6.27 (44.03)	4.25 (19.84)	6.14 (42.27)	7.37 (61.73)	6.06 (41.97)
SEd	0.27	0.19	0.46	0.43	0.43	0.26	0.16	0.41	0.35	0.35	0.28	0.19	0.47	0.43	0.43
CD (5%)	0.64	0.39	1.00	0.89	0.89	0.62	0.33	0.89	0.74	0.74	0.66	0.40	1.09	0.89	0.89

Figures in parenthesis are original values
T₁ - T₅ : Preparatory tillages
W₁ - W₄ : Weed management methods

4.1.3. Group wise weed density

Sunflower

4.1.3.1.Grasses

Significant effect was observed with both preparatory tillage and weed management methods on the influence of density of grassy weeds at all the growth stages of sunflower (Table 20). Either country plough tillage twice (T₁) or cultivator tillage twice (T₂) recorded the lowest density of grasses, while minimum tillage (T₅) registered the highest density at all the growth stages. However, T₅ was comparable with that of both mould board ploughing (T₃) and disc ploughing (T₄) followed by cultivator tillage twice at 60 DAS and with that of T₃ alone at harvest stage. Significant variation was observed between T₃ and T₄ at 30 DAS, which were on par with each other at harvest stage.

Among the weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS registered the lowest density of grasses, whereas, unweeded control (W₄) resulted in the highest density at all the growth stages. Both hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS were superior to unweeded control and were on par with each other at all the growth stages.

Density of grasses was not significantly influenced by the interaction effect between the preparatory tillage and weed management methods.

4.1.3.2.Sedge

Significant effect of both preparatory tillage and weed management methods was found on the density of sedge weed (Table 20). Both country plough tillage twice (T₁) and cultivator tillage twice (T₂) resulted in the lowest density of the sedge weed both at 30 and 60 DAS. However, T₁ and T₂ were on par with minimum tillage (T₅) at harvest stage. Disc ploughing followed by cultivator tillage twice (T₄) recorded the highest density of sedge which was on par with mould board ploughing followed by cultivator tillage twice (T₃) at all the growth stages except at 30 DAS.

Table 20. Effect of preparatory tillage and weed management methods on group wise weed density in sunflower (No./m²)

Treatment	30 DAS				60 DAS				Harvest			
	Grasses	Sedge	BLW	Total	Grasses	Sedge	BLW	Total	Grasses	Sedge	BLW	Total
T ₁	5.63 (43.30)	3.68 (15.35)	8.65 (89.74)	11.06 (148.40)	5.83 (41.4)	4.36 (21.12)	11.33 (149.41)	13.51 (211.94)	5.44 (33.84)	4.63 (23.69)	11.72 (161.37)	13.78 (218.91)
T ₂	5.56 (42.78)	3.75 (16.05)	8.45 (85.54)	10.89 (144.38)	5.65 (39.13)	4.57 (23.53)	11.26 (147.70)	13.45 (210.43)	5.21 (30.77)	4.55 (23.12)	12.06 (166.35)	13.92 (220.25)
T ₃	6.18 (49.76)	3.83 (16.52)	6.39 (46.83)	9.76 (113.12)	6.50 (49.43)	5.02 (29.43)	8.63 (83.68)	11.94 (162.52)	6.15 (42.03)	5.12 (29.93)	9.06 (92.86)	12.11 (164.82)
T ₄	5.90 (45.50)	4.14 (19.35)	6.05 (41.86)	9.49 (106.72)	6.26 (46.13)	5.11 (29.40)	8.19 (75.23)	11.53 (150.77)	5.90 (38.78)	5.21 (30.11)	8.39 (79.33)	11.51 (148.22)
T ₅	6.45 (54.57)	3.93 (17.70)	8.91 (95.57)	11.78 (167.92)	6.47 (49.27)	4.63 (24.06)	11.65 (158.67)	14.15 (232.01)	6.22 (43.16)	4.74 (24.79)	11.69 (159.44)	14.13 (227.39)
SEd	0.11	0.05	0.41	0.29	0.11	0.09	0.50	0.34	0.13	0.09	0.52	0.36
CD (5%)	0.26	0.12	0.96	0.67	0.27	0.22	1.17	0.79	0.31	0.20	1.21	0.84
W ₁	5.12 (28.83)	3.84 (16.20)	8.21 (76.02)	10.46 (121.05)	5.59 (34.37)	4.57 (22.92)	11.04 (137.16)	13.26 (194.51)	5.37 (31.75)	4.52 (22.49)	11.06 (137.35)	13.16 (191.59)
W ₂	3.05 (10.30)	2.96 (9.68)	4.22 (19.53)	6.00 (39.52)	4.09 (18.54)	3.64 (14.58)	6.57 (47.34)	8.57 (80.46)	4.87 (26.33)	4.19 (19.32)	6.97 (53.62)	9.51 (99.28)
W ₃	5.13 (29.12)	3.79 (15.78)	8.28 (72.71)	10.53 (122.68)	5.82 (37.25)	4.86 (25.96)	10.49 (123.76)	13.01 (186.98)	5.66 (35.28)	4.94 (26.83)	10.83 (131.82)	13.25 (193.93)
W ₄	10.48 (120.48)	4.89 (26.32)	10.05 (114.77)	15.39 (261.17)	9.07 (90.12)	5.89 (38.57)	12.75 (183.50)	16.82 (312.19)	7.24 (57.29)	5.75 (36.67)	13.49 (204.70)	16.44 (298.87)
SEd	0.43	0.11	0.35	0.53	0.28	0.13	0.38	0.47	0.14	0.10	0.38	0.40
CD (5%)	0.89	0.22	0.72	1.08	0.58	0.27	0.77	0.96	0.29	0.20	0.79	0.81
T at W	0.85	0.22	0.80	1.07	0.57	0.28	0.89	0.98	0.30	0.21	0.91	0.85
CD (5%)	NS	NS	1.69	NS	NS	0.58	1.90	NS	NS	0.45	1.95	NS
W at T SEd	0.97	0.24	0.79	1.19	0.64	0.30	0.85	1.05	0.31	0.22	0.86	0.89
CD (5%)	NS	NS	1.62	NS	NS	0.62	1.73	NS	NS	0.46	1.77	NS

Figures in parenthesis are original values BLW – Broad-leaved weeds
T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

In case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the lowest density of sedge and unweeded control (W_4) registered the highest density at all the growth stages. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were significantly superior to W_4 , but were on par with each other in recording higher density of sedge at all the stages of observation.

Interaction effect between preparatory tillage and weed management methods was found to be significant at 60 DAS and at harvest (Table 21). Cultivator tillage in combination with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (T_2W_2) resulted in the lowest density of sedge. However, T_2W_2 was comparable with that of the combination of W_2 with other tillage methods (T_1W_2 , T_3W_2 , T_4W_2 and T_5W_2) at 60 DAS and T_2W_2 was on par with the combination of W_2 either with country plough tillage twice (T_1W_2) or with mould board ploughing followed by cultivator tillage twice at harvest (T_3W_2). Highest density was registered with the combination of unweeded control with T_3 (T_3W_4) both at 60 DAS and at harvest stage.

4.1.3.3. Broad-leaved weeds

Preparatory tillage and weed management methods significantly influenced the density of broad-leaved weeds (Table 20). Either mould board ploughing (T_3) or disc ploughing (T_4) followed by cultivator tillage twice recorded the lowest density, whereas, minimum tillage (T_5) registered the highest density of broad-leaved weeds at all the growth stages. However, the highest density of broad-leaved weeds in T_5 was comparable with that of both country plough tillage twice (T_1) and cultivator tillage twice (T_2) at all the growth stages of observation.

Among the weed management methods, the lowest density of broad leaved weeds was observed with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS and unweeded control (W_4) recorded the highest density of broad leaved weeds at all the three stages. Either hand weeding twice (W_1) or

Table 21. Interaction effect of preparatory tillage and weed management methods on density of sedge weed (No./m²) in sunflower

Treatment	60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	4.44 (21.58)	3.52 (13.63)	4.65 (23.69)	4.83 (25.61)	4.36 (21.12)	4.49 (22.09)	4.07 (18.21)	4.84 (25.64)	5.13 (28.85)	4.63 (23.69)
T ₂	4.57 (22.80)	3.40 (12.65)	4.77 (24.97)	5.54 (33.65)	4.57 (23.53)	4.34 (20.66)	3.80 (15.88)	4.62 (23.44)	5.45 (32.52)	4.55 (23.12)
T ₃	4.59 (23.09)	3.47 (13.23)	5.00 (27.37)	7.02 (54.04)	5.02 (29.43)	4.50 (22.23)	4.06 (18.11)	4.03 (27.78)	6.86 (51.60)	5.12 (29.93)
T ₄	4.91 (26.40)	3.96 (17.21)	5.35 (31.42)	6.23 (42.51)	5.11 (29.40)	4.91 (26.39)	4.51 (22.35)	5.43 (32.38)	5.99 (39.33)	5.21 (30.11)
T ₅	4.35 (20.71)	3.84 (16.21)	4.52 (22.38)	5.81 (36.96)	4.63 (24.06)	4.38 (21.08)	4.48 (22.09)	4.77 (24.91)	5.33 (31.09)	4.74 (24.79)
Mean	4.57 (22.92)	3.64 (14.58)	4.86 (25.96)	5.89 (38.57)	4.74 (25.51)	4.52 (22.48)	4.19 (19.32)	4.95 (26.83)	5.75 (36.67)	4.85 (26.33)
	T	W	T at W	W at T	T	W	T at W	W at T		
SEd	0.09	0.13	0.28	0.30	0.09	0.10	0.21	0.22		
CD (5%)	0.22	0.27	0.58	0.62	0.20	0.20	0.45	0.46		

Figures in parenthesis are original values
T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

mechanical weeding twice (W_3) on 20 and 40 DAS was proved significantly superior to unweeded control (W_4) and both were on par with each other at all the growth stages.

Significant interaction effect was observed between preparatory tillage and weed management methods at all the growth stages (Table 22). Preparatory tillage with disc ploughing followed by cultivator tillage twice in combination with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (T_4W_2) resulted in the lowest density of broad-leaved weeds at all the growth stages. However, T_4W_2 was comparable with all other tillage methods in combination with herbicidal + manual weeding (T_1W_2 , T_2W_2 , T_3W_2 and T_5W_2) at 30 and 60 DAS and on par with combination of W_2 with country plough tillage twice (T_1W_2), mould board ploughing followed by cultivator tillage twice (T_3W_2) and minimum tillage in combination with herbicide + hand weeding (T_5W_2) at harvest stage. Highest density of broad-leaved weeds was registered with minimum tillage combined with unweeded control (T_5W_4), which was comparable with that of either country plough tillage twice (T_1W_4) or cultivator tillage twice in combination with unweeded control (T_2W_4) at all the growth stages.

4.1.3.4. Total weeds

The density of total weeds was significantly affected both by preparatory tillage and weed management methods (Table 20). Preparatory tillage with disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice recorded the lowest density of total weeds. However, the highest density of total weeds was observed with minimum tillage (T_5) at all growth stages. But, the highest density in T_5 was comparable with that of both country plough tillage twice (T_1) and cultivator tillage twice (T_2) at 60 DAS and at harvest. Comparable reduction in density of total weeds was observed with both T_1 and T_2 , which were significantly superior to T_5 at 30 DAS in recording lesser total weeds.

In case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS recorded the lowest density of total weeds. The highest density of total weeds was recorded with unweeded control (W_4) at all the growth stages. Both hand weeding twice (W_1) and mechanical weeding

Table 22. Interaction effect of preparatory tillage and weed management methods on density of broad leaved weeds (No./m²) in sunflower

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	9.34 (95.58)	4.27 (20.01)	9.60 (101.02)	11.40 (142.38)	8.65 (89.74)	12.46 (170.03)	6.67 (48.82)	11.79 (52.21)	14.39 (226.91)	11.33 (149.41)	12.50 (171.01)	6.63 (48.13)	12.53 (172.01)	15.24 (254.36)	11.72 (161.37)
T ₂	9.19 (92.46)	4.22 (19.51)	9.11 (90.84)	11.28 (139.38)	8.45 (85.54)	12.48 (170.59)	6.60 (47.78)	11.70 (150.01)	14.25 (222.45)	11.26 (147.70)	12.36 (167.31)	8.19 (73.41)	12.47 (170.28)	15.24 (254.41)	12.06 (166.35)
T ₃	6.65 (48.51)	4.20 (19.31)	6.70 (49.21)	8.01 (70.31)	6.39 (46.83)	9.08 (90.31)	6.51 (46.46)	8.67 (82.40)	10.27 (115.55)	8.63 (83.68)	9.14 (91.42)	6.64 (48.30)	9.21 (92.97)	11.26 (138.77)	9.06 (92.86)
T ₄	6.28 (43.24)	4.11 (18.50)	6.21 (42.31)	7.61 (63.42)	6.0 (541.86)	8.57 (80.37)	6.31 (43.60)	8.12 (72.15)	9.78 (104.81)	8.19 (75.23)	8.64 (81.80)	6.35 (44.26)	8.20 (73.64)	10.36 (117.62)	8.39 (79.33)
T ₅	9.57 (100.35)	4.31 (20.36)	9.80 (105.21)	11.95 (156.38)	8.91 (95.57)	12.62 (174.50)	6.76 (50.07)	12.16 (162.04)	15.05 (248.10)	11.65 (158.67)	12.65 (175.21)	7.02 (54.01)	11.71 (150.21)	15.36 (258.34)	11.69 (159.44)
Mean	8.21 (76.02)	4.22 (19.53)	8.28 (77.71)	10.05 (114.37)	7.69 (71.90)	11.04 (137.16)	6.57 (47.34)	10.49 (123.76)	12.75 (183.50)	10.21 (122.94)	11.06 (137.35)	6.97 (53.62)	10.83 (131.82)	13.49 (204.70)	10.58 (131.87)
SEd	T	W	T at W	W at T	T	W	T at W	W at T	T	W	T at W	W at T	T	W	W at T
	0.41	0.35	0.80	0.79	0.50	0.38	0.89	0.85	0.52	0.38	0.91	0.86	0.52	0.38	0.86
CD (5%)	0.96	0.72	1.69	1.62	1.17	0.77	1.90	1.73	1.21	0.79	1.95	1.77	1.21	0.79	1.77

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

twice (W_2) on 20 and 40 DAS were significantly superior to unweeded control (W_4) and both were on par with each other at all the growth stages.

There was no significant interaction effect between preparatory tillage and weed management methods on the density of total weeds.

4.1.4. Group wise weed density

Maize

4.1.4.1. Grasses

Preparatory tillage and weed management methods significantly influenced the density of grasses (Table 23). Either country plough tillage twice (T_1) or cultivator tillage twice (T_2) recorded the lowest density of grasses at all the stages. Whereas, the highest density of grasses was registered with minimum tillage (T_5) at all the growth stages. However, the grass weed density with T_5 was comparable with that of mould board tillage followed by cultivator tillage twice (T_3) both at 30 and 60 DAS. Disc ploughing followed by cultivator tillage twice (T_4) was found to be superior to T_5 and was on par with T_3 at all growth stages.

Among the weed management methods, lowest density of grasses was recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2). Unweeded control (W_4) registered the highest density of grasses at all the stages of observation. Hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were found to register more grassy weeds than in W_2 , W_1 and W_3 were on par at all growth stages.

Significant interaction effect was observed between preparatory tillage and weed management methods on grass weeds only at harvest stage (Table 24). Mould board ploughing followed by cultivator tillage twice in combination with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_3W_2) resulted in the lowest density which was comparable with that of country plough tillage twice combined either with hand weeding twice (T_1W_1) or with herbicide + manual weeding (T_1W_2). Cultivator tillage twice with either manual weeding twice (T_2W_1), or herbicidal + manual weeding (T_2W_2), or with mechanical weeding twice (T_2W_3) registered comparable grassy weeds with the disc

Table 23. Effect of preparatory tillage and weed management methods on group wise weed density in maize (No./m²)

Treatment	30 DAS				60 DAS				Harvest			
	Grasses	Sedge	BLW	Total	Grasses	Sedge	BLW	Total	Grasses	Sedge	BLW	Total
T ₁	5.20 (37.20)	3.69 (15.35)	8.08 (26.20)	10.38 (128.76)	5.39 (35.46)	4.35 (20.96)	10.06 (116.41)	12.26 (172.84)	5.04 (29.03)	4.50 (22.48)	10.40 (125.21)	12.43 (176.74)
T ₂	5.06 (35.43)	3.52 (14.24)	8.08 (77.07)	10.01 (119.25)	5.10 (31.92)	4.26 (20.55)	10.40 (121.53)	12.39 (174.01)	4.72 (25.11)	4.32 (20.73)	10.15 (118.98)	12.08 (164.83)
T ₃	5.82 (44.66)	3.86 (16.91)	5.78 (38.24)	9.14 (99.82)	6.09 (43.86)	5.06 (30.29)	7.92 (69.65)	11.24 (143.80)	5.43 (33.32)	5.33 (33.13)	8.24 (75.49)	11.24 (141.94)
T ₄	5.53 (41.21)	4.01 (18.21)	5.44 (33.71)	8.82 (93.13)	5.82 (40.81)	4.66 (24.61)	7.44 (61.36)	10.57 (126.79)	5.12 (29.37)	4.75 (25.60)	7.76 (66.78)	10.45 (121.76)
T ₅	6.33 (53.92)	3.88 (17.36)	8.47 (86.02)	11.34 (157.31)	6.28 (47.42)	4.59 (23.68)	10.36 (122.54)	13.00 (193.65)	5.90 (39.85)	4.78 (25.62)	11.07 (140.65)	13.44 (206.12)
SEd	0.15	0.05	0.44	0.30	0.15	0.09	0.44	0.29	0.13	0.11	0.44	0.35
CD (5%)	0.35	0.13	1.01	0.71	0.34	0.22	1.01	0.68	0.31	0.26	1.01	0.81
W ₁	4.70 (24.49)	3.73 (15.31)	7.58 (65.27)	9.74 (105.08)	5.10 (28.90)	4.38 (21.11)	9.66 (104.94)	11.85 (154.95)	4.94 (27.13)	4.68 (24.12)	9.91 (110.10)	12.09 (161.36)
W ₂	2.88 (9.16)	2.82 (8.73)	4.26 (20.05)	5.88 (37.95)	3.83 (16.24)	3.56 (14.00)	6.85 (51.70)	8.64 (81.94)	4.13 (18.77)	3.95 (17.30)	6.72 (49.63)	8.84 (85.71)
W ₃	4.69 (24.38)	3.72 (15.21)	7.43 (62.76)	9.60 (102.35)	5.32 (31.19)	4.52 (22.49)	9.28 (96.68)	11.66 (150.36)	5.15 (29.24)	4.48 (22.35)	9.70 (105.63)	11.92 (157.23)
W ₄	10.09 (111.90)	4.90 (26.41)	9.41 (100.92)	14.53 (233.24)	8.70 (83.25)	5.86 (38.48)	11.16 (139.87)	15.42 (261.61)	6.74 (50.20)	5.83 (38.27)	11.77 (156.34)	14.87 (244.81)
SEd	0.42	0.11	0.30	0.49	0.28	0.14	0.26	0.38	0.15	0.13	0.31	0.34
CD (5%)	0.87	0.24	0.63	1.00	0.58	0.29	0.53	0.79	0.31	0.27	0.63	0.71
T at W SEd	0.84	0.23	0.74	1.00	0.57	0.29	0.67	0.80	0.33	0.28	0.74	0.76
CD (5%)	NS	NS	1.58	NS	NS	0.61	1.45	NS	0.69	0.60	1.59	NS
W at T SEd	0.95	0.26	0.69	1.01	0.64	0.32	0.59	0.86	0.35	0.30	0.69	0.78
CD (5%)	NS	NS	1.40	NS	NS	0.66	1.20	NS	0.71	0.62	1.42	NS

Figures in parenthesis are original values BLW – Broad-leaved weeds

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

Table 24. Interaction effect of preparatory tillage and weed management methods on density of grasses at harvest and sedge weed (No./m²) in maize at 60 DAS and harvest

Treatment	Grasses					Sedge									
	Harvest					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	4.24 (19.72)	4.01 (17.67)	5.17 (29.32)	6.72 (49.44)	5.04 (29.03)	4.35 (20.72)	3.63 (14.45)	4.61 (23.30)	4.81 (25.37)	4.35 (20.96)	4.58 (22.98)	3.70 (15.05)	4.79 (25.14)	4.94 (26.78)	4.50 (22.48)
T ₂	4.29 (20.20)	4.10 (18.42)	4.42 (21.47)	6.07 (40.36)	4.72 (25.11)	4.23 (19.66)	3.13 (10.77)	4.42 (21.44)	5.26 (30.36)	4.26 (20.55)	4.55 (22.67)	4.62 (23.42)	3.49 (13.36)	4.63 (23.49)	4.72 (20.73)
T ₃	5.46 (32.72)	3.98 (17.41)	5.61 (34.52)	6.66 (48.64)	5.43 (33.32)	4.57 (22.96)	3.41 (12.76)	4.90 (26.37)	7.35 (59.17)	5.06 (30.29)	5.27 (30.48)	3.55 (13.81)	5.09 (28.42)	7.39 (59.81)	5.33 (33.13)
T ₄	5.16 (29.24)	4.07 (18.14)	4.95 (26.89)	6.28 (43.24)	5.12 (29.37)	4.6 (23.89)	3.81 (15.92)	4.06 (18.10)	6.08 (40.55)	4.66 (24.61)	4.77 (24.91)	3.82 (16.05)	4.18 (19.14)	6.21 (42.31)	4.75 (25.60)
T ₅	5.55 (33.81)	4.50 (22.24)	5.57 (34.01)	7.96 (69.34)	5.90 (39.85)	4.10 (18.42)	3.83 (16.10)	4.60 (23.25)	5.81 (36.96)	4.59 (23.68)	4.23 (19.58)	4.07 (18.21)	4.84 (28.72)	5.96 (38.97)	4.78 (25.62)
Mean	4.94 (27.13)	4.13 (18.77)	5.15 (29.24)	6.74 (50.20)	5.24 (31.33)	4.38 (21.11)	3.56 (14.00)	4.52 (22.49)	5.86 (38.48)	4.58 (24.01)	4.68 (24.12)	3.95 (17.30)	4.48 (22.35)	5.83 (38.27)	4.81 (25.51)
	T	W	T at W	W at T	T	W	T at W	W at T	T	W	T at W	W at T	T	W	W at T
SEd	0.13	0.15	0.33	0.35	0.09	0.14	0.29	0.32	0.11	0.13	0.28	0.30			
CD (5%)	0.31	0.31	0.69	0.71	0.22	0.29	0.61	0.66	0.26	0.27	0.60	0.62			

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

ploughing followed by cultivator tillage twice (T_4W_2) or minimum tillage coupled with herbicidal + manual weeding (T_5W_2). The highest density of grasses was recorded with minimum tillage combined with unweeded control (T_5W_4) at harvest.

4.1.4.2. Sedge

Density of sedge was significantly influenced both by preparatory tillage and weed management methods (Table 23). Cultivator tillage twice (T_2) registered the lowest density at all the growth stages, which was on par with that of country plough tillage twice (T_1) at 60 DAS and at harvest. Highest density of sedge was recorded with disc ploughing followed by cultivator tillage twice (T_4) at 30 DAS, which was comparable with that of minimum tillage (T_5) at 30 DAS. Mould board ploughing followed by cultivator tillage twice (T_3) recorded the highest density of sedge weed both at 60 DAS as well as at harvest. Both T_4 and T_5 were on par and significantly superior to T_3 at 60 DAS and at harvest, while the effect of T_5 on the density of sedge was comparable with that of T_3 at 30 DAS.

Significant variation was observed in the density of sedge by weed management methods. Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the lowest density, while unweeded control (W_4) registered the highest density at all the three stages. Either hand weeding twice (W_1) or mechanical weeding twice (W_3) were significantly superior to unweeded control (W_4) and were on par with each other by recording higher density of sedge than in W_2 .

Significant interaction was observed between preparatory tillage and weed management methods both at 60 DAS and at harvest (Table 24). Lowest density of sedge was recorded with the combination of cultivator tillage twice and pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_2W_2) which was comparable with that of either country plough tillage twice (T_1W_2) or mould board ploughing followed by cultivator tillage twice (T_3W_2) in combination with herbicide + hand weeding at 60 DAS. However, at harvest stage, the lowest density of sedge was recorded with mechanical weeding twice in combination with herbicide + hand weeding (T_2W_3) which was comparable with the combination of T_1W_2 as well as T_3W_2 . Disc ploughing followed by cultivator tillage (T_4W_2)

or minimum tillage (T_5W_2) coupled with herbicidal + manual weeding recorded comparable density of sedge with T_2W_3 . Highest density of sedge was found with the combination of mould board ploughing followed by cultivator tillage twice with unweeded check ($T_3 W_4$) both at 60 DAS and at harvest.

4.1.4.3. Broad-leaved weeds

Density of broad-leaved weeds was significantly influenced both by preparatory tillage and weed management methods (Table 23). Either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice recorded the lowest density of broad-leaved weeds. Whereas, minimum tillage (T_5) recorded the highest density at all the growth stages. However, the highest density with T_5 was found to be on par with that of either country plough tillage twice (T_1) or cultivator tillage twice (T_2) at all the growth stages.

Among weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) resulted in the lowest density of broad-leaved weeds, while unweeded control (W_4) recorded the highest density at all the three stages. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were on par in reducing the broad-leaved weeds but the density was more than W_2 at all the stages of observation.

Significant interaction effect was noticed between preparatory tillage and weed management methods on the density of broad-leaved weeds at 30 and 60 DAS as well as at harvest (Table 25). Disc ploughing followed by cultivator tillage twice in combination with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_4W_2) recorded the lowest density at 30 and 60 DAS, whereas, herbicide + manual weeding combined with cultivator tillage twice (T_2W_2) resulted in the lowest density at harvest stage. The lowest density of $T_4 W_2$ was comparable with that of other tillage methods combined with W_2 (T_1W_2 , T_2W_2 , T_3W_2 and T_4W_2) at 30 DAS. Country plough tillage twice (T_1W_2) or mould board ploughing followed by cultivator tillage twice (T_3W_2) or minimum tillage (T_5W_2) in combination with herbicidal + manual weeding recorded comparable density of broad leaved weeds with T_4W_1 or T_4W_3 at 60 DAS. Similar density of broad-leaved weeds

Table 25. Interaction effect of preparatory tillage and weed management methods on density of broad-leaved weeds (No./m²) in maize

Treatment	30 DAS					60 DAS					Harvest				
	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean	W ₁	W ₂	W ₃	W ₄	Mean
T ₁	8.62 (81.38)	4.76 (24.82)	8.45 (78.31)	10.48 (120.32)	8.08 (76.20)	10.72 (125.98)	6.49 (46.12)	10.36 (117.54)	12.68 (176.01)	10.06 (116.41)	10.81 (127.89)	6.48 (46.01)	10.90 (130.05)	13.41 (196.92)	10.40 (125.21)
T ₂	8.56 (80.31)	4.56 (22.80)	8.35 (76.34)	10.85 (128.86)	8.08 (77.07)	10.80 (127.84)	7.75 (65.78)	10.72 (125.97)	12.33 (166.54)	10.40 (121.53)	10.81 (128.01)	6.21 (42.21)	10.95 (131.42)	12.62 (174.31)	10.15 (118.98)
T ₃	5.99 (39.34)	3.98 (17.38)	5.73 (35.94)	7.42 (60.32)	5.78 (38.24)	8.00 (70.14)	6.64 (48.32)	7.75 (65.84)	9.28 (94.31)	7.92 (69.65)	8.46 (78.49)	6.78 (50.31)	8.15 (72.81)	9.57 (100.38)	8.24 (75.49)
T ₄	5.65 (35.02)	3.72 (15.21)	5.59 (34.24)	6.78 (50.38)	5.44 (33.71)	7.54 (62.31)	6.35 (44.14)	7.20 (56.82)	8.66 (82.17)	7.44 (61.36)	7.76 (65.91)	6.68 (48.84)	7.59 (63.15)	9.03 (89.24)	7.76 (66.78)
T ₅	9.08 (90.31)	4.27 (20.04)	9.01 (88.98)	11.50 (144.76)	8.47 (78.56)	11.24 (138.46)	7.03 (54.14)	10.35 (117.25)	12.83 (180.34)	10.3612 2.54	11.71 (150.21)	7.45 (60.79)	10.93 (130.74)	14.20 (220.86)	11.07 (140.65)
Mean	7.58 (65.27)	4.26 (20.05)	7.43 (62.76)	9.41 (100.92)	7.12 (62.25)	9.66 (104.94)	6.85 (51.70)	9.28 (96.68)	11.16 (139.87)	9.23 (98.29)	9.91 (110.10)	6.72 (49.63)	9.70 (105.63)	11.77 (156.34)	9.52 (105.42)
SED	0.44	0.30	0.74	0.69		0.44	0.26	0.67	0.59		0.44	0.31	0.74	0.69	
CD (5%)	1.01	0.63	1.58	1.40		1.01	0.53	1.45	1.20		1.01	0.63	1.59	1.42	

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages W₁ - W₄ : Weed management methods

with T_2W_2 was observed with that of T_1W_2 , T_3W_2 , T_4W_2 and T_4W_3 at harvest stage. Highest density of broad-leaved weeds was recorded by the combination of minimum tillage with unweeded control (T_5W_4) at all the stages. However, the broad-leaved weed density with T_5W_4 was comparable either with that of country plough tillage twice (T_1W_4) or with cultivator tillage twice in combination with unweeded control (T_2W_4) at 30 and 60 DAS and on par with T_1W_4 alone at harvest stage.

4.1.4.4. Total weeds

Both preparatory tillage and weed management methods significantly influenced the density of total weeds (Table 23). Either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice registered the lowest density of total weeds, while minimum tillage (T_5) recorded the highest density at all the growth stages. However, T_5 was on par with that of cultivator tillage twice (T_2) at 60 DAS alone. Both country plough tillage twice (T_1) and cultivator tillage twice (T_2) were significantly superior to minimum tillage (T_5) at 30 DAS as well as harvest and both were on par with each other at all the growth stages of observation.

Among the weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) registered the lowest density of total weeds, while unweeded control found to record the highest density at 30 and 60 DAS as well as at harvest. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were on par with each other and significantly superior to unweeded control in recording lesser total weed density at all the growth stages of maize.

There was no significant interaction effect between preparatory tillage and weed management methods on the density of total weeds.

4.1.5. Relative density of individual weeds

Sunflower

30 DAS : The proportion of individual weed species observed under both with country plough tillage twice (T_1) and cultivator tillage twice (T_2) was relatively comparable with each other (Table 26). Among fifteen species observed in the field, *Trianthema portulacastrum* was predominant one with a relative density of 17.33% in country plough tillage twice (T_1) and 16.19% with cultivator tillage twice (T_2) at 30 DAS. Whereas, *Cynodon dactylon* was in predominant proportion with a relative density of 20.61% closely followed by *Cyperus rotundus* 16.82% in mould board ploughing followed by cultivator tillage twice (T_3) at 30 DAS. Disc ploughing followed by cultivator tillage twice (T_4) resulted in the highest proportion (20.58%) of *Cyperus rotundus* with closer range of 19.96% of *Cynodon dactylon* among the tillage methods. Minimum tillage (T_5) registered comparable proportion of *Cynodon dactylon* (15.65%) and *Trianthema portulacastrum* (15.97%) closely followed by only sedge *Cyperus rotundus* (13.86%) at 30 DAS in sunflower. Proportion of *Cyperus rotundus* was higher with a relative density of 24.37% with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha (W_2) among the weed management methods at 30 DAS. Highest relative density of *Cynodon dactylon* was recorded with unweeded control (W_4) among all the individual species. Among the different weed species, *Trianthema portulacastrum* (16.98 and 17.12%), *Cynodon dactylon* (13.59 and 13.41%) and *Cyperus rotundus* (14.14 and 13.75%) were in the dominant and comparable proportion with manual weeding twice (W_1) and mechanical weeding twice (W_3) at 30 DAS in sunflower.

60 DAS : Among the broad-leaved weeds, *Trianthema portulacastrum* was in higher proportion with 19.48% relative density both in country plough tillage twice (T_1) and cultivator tillage twice (T_2) and minimum tillage (T_5) also recorded a higher proportion (18.75%) compared to other two deep tillage methods (Table 27). Highest density of *Cyperus rotundus* (17.43%) was observed in mould board ploughing followed by cultivator tillage twice (T_3) and *Cynodon dactylon* was also predominant with 15.75% relative density at 60 DAS in T_3 . *Cyperus rotundus* was the most dominant weed with 19.93% relative density in disc ploughing followed by cultivator tillage (T_4) in sunflower at 60 DAS. Whereas, minimum tillage (T_5) recorded the highest proportion of *Trianthema portulacastrum* (18.76%) among

Table 26. Relative density (%) of individual weeds as influenced by preparatory tillage and weed management methods in sunflower at 30 DAS

Treatments	CD	DE	OG	CR	PH	TP	DA	OBLW
T ₁	13.59	6.20	5.02	13.16	8.07	17.33	11.78	24.81
T ₂	13.64	6.33	5.02	13.83	7.94	16.91	11.51	24.78
T ₃	20.61	9.38	8.15	16.82	5.81	12.51	8.48	18.20
T ₄	19.96	9.13	7.50	20.58	5.54	11.85	8.03	17.36
T ₅	15.65	7.15	5.96	13.86	7.40	15.97	10.83	23.06
W ₁	13.59	6.22	5.02	14.14	7.89	16.98	11.52	24.60
W ₂	13.92	6.43	5.55	24.37	6.41	13.72	9.33	20.23
W ₃	13.41	6.13	5.19	13.75	8.00	17.12	11.62	24.69
W ₄	25.85	11.77	9.57	10.35	5.51	11.84	8.03	17.04

Table 27. Relative density (%) of individual weeds as influenced by preparatory tillage and weed management methods in sunflower at 60 DAS

Treatments	CD	DE	OG	CR	PH	TP	DA	OBLW
T ₁	10.06	4.57	3.82	11.59	9.05	19.48	13.22	28.17
T ₂	9.45	4.30	3.90	12.35	9.04	19.48	13.22	28.22
T ₃	15.75	7.16	6.24	17.43	6.90	14.87	10.09	27.02
T ₄	15.56	7.07	6.18	19.93	6.61	14.24	9.6	20.71
T ₅	11.44	5.20	4.53	11.71	8.71	18.76	12.73	26.89
W ₁	10.14	4.61	3.97	12.49	8.91	19.19	13.02	27.63
W ₂	12.07	5.48	5.31	18.11	7.58	16.33	11.08	24.03
W ₃	11.31	5.14	4.37	14.68	8.36	18.02	12.23	30.22
W ₄	16.29	7.40	6.09	13.13	7.39	15.92	10.80	22.93

Data statistically not analysed

CD – *Cynodon dactylon*; DE – *Dactyloctenium aegyptium*; OG – Other grasses;

CR – *Cyperus rotundus*; PH – *Parthenium hysterophorus*; TP – *Trianthema portulacastrum*;

DA – *Digera arvensis*; OBLW – Other broad leaved weeds

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

the dominant weeds. *Cynodon dactylon* was dominant weed (16.29%) in unweeded control (W₄) among the grasses and *Trianthema portulacastrum* (15.92%) among the broad-leaved weeds at 60 DAS. Relative density of *Trianthema portulacastrum* was higher (19.19%) with hand weeding twice (W₁) closely followed by mechanical weeding (W₃). *Cyperus rotundus* (18.11%) and *Trianthema portulacastrum* (16.33%) were the dominant weeds with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂) among the weed management methods at 60 DAS in sunflower.

Harvest : Predominance of *Trianthema portulacastrum* was observed both with country plough tillage twice (T₁) (19.84%) and cultivator tillage twice (T₂) (20.87%) among the tillage methods (Table 28). Disc ploughing followed by cultivator tillage twice (T₄) resulted in higher proportion (20.83%) of sedge weed *Cyperus rotundus* closely followed by cultivator tillage (T₃) with relative density of 17.76% among the dominant weeds. However, minimum tillage (T₅) maintained higher proportion of *Trianthema portulacastrum* (18.76%) even at harvest stage of sunflower.

Higher proportion of *Trianthema portulacastrum* was observed with hand weeding twice (W₁) (19.59%) or with unweeded control (W₄) (18.69%) as well as with mechanical weeding twice (W₃) (18.53%) at harvest. Sedge *Cyperus rotundus* was higher in percentage among the dominant weeds with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂). *Cynodon dactylon* was the predominant grass observed among the grassy weeds with unweeded control (W₄) at harvest.

Maize

30 DAS: In maize *Cyperus rotundus* was in dominant proportion among all the weeds with different preparatory tillage methods (Table 29). Either mould board ploughing (T₃) or disc ploughing (T₄) followed by cultivator tillage recorded higher proportion of *Cyperus rotundus* (31.25 and 30.79%). Next to *Cyperus rotundus*, *Trianthema portulacastrum* was in dominant proportion recording a relative density of 16.17 and 16.84% with country plough tillage twice (T₁) and cultivator tillage twice (T₂), respectively at 30 DAS. Whereas, *Cynodon*

Table 28. Relative density (%) of individual weeds as influenced by preparatory tillage and weed management methods in sunflower at harvest

Treatments	CD	DE	OG	CR	PH	TP	DA	OBLW
T ₁	9.02	4.09	3.28	12.72	9.21	19.84	13.46	27.66
T ₂	7.86	3.57	2.85	11.12	9.69	20.87	14.16	29.82
T ₃	14.56	6.61	5.29	17.76	7.24	15.60	10.58	22.29
T ₄	14.51	6.59	5.27	20.83	6.85	14.77	10.02	21.10
T ₅	11.28	5.12	4.10	12.45	8.71	18.76	12.73	26.80
W ₁	9.65	4.38	3.51	12.43	9.09	19.59	13.29	27.45
W ₂	14.60	6.63	5.30	19.63	6.98	15.06	10.21	21.51
W ₃	10.53	4.78	3.82	14.63	8.60	18.53	12.57	26.47
W ₄	10.99	4.99	3.99	13.21	8.68	18.69	12.68	26.71

Table 29. Relative density (%) of individual weeds as influenced by preparatory tillage and weed management methods in maize at 30 DAS

Treatments	CD	DE	OG	CR	PH	TP	DA	OBLW
T ₁	13.26	6.15	4.25	21.03	9.32	16.17	11.81	24.87
T ₂	13.50	6.27	4.33	19.81	9.72	16.84	12.31	25.92
T ₃	21.39	9.92	6.87	31.25	6.36	11.02	8.06	16.97
T ₄	20.64	9.57	6.63	30.79	6.10	10.57	7.72	16.27
T ₅	16.60	7.70	5.32	20.58	8.50	14.75	10.77	22.70
W ₁	13.67	6.34	4.39	21.44	9.01	15.61	11.41	24.03
W ₂	13.58	6.30	4.35	37.00	7.87	13.65	9.97	21.01
W ₃	13.91	6.45	4.46	22.99	8.88	15.39	11.24	23.69
W ₄	27.15	12.60	8.72	17.33	6.25	10.83	7.92	16.67

Data statistically not analysed

CD – *Cynodon dactylon*; DE – *Dactyloctenium aegyptium*; OG – Other grasses;

CR – *Cyperus rotundus*; PH – *Parthenium hysterophorus*; TP – *Trianthema portulacastrum*;

DA – *Digera arvensis*; OBLW – Other broad leaved weeds

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

dactylon was in next with a relative density of 21.39% in mould board ploughing (T₃) and disc ploughing (T₄) followed by cultivator tillage, respectively next to *Cyperus rotundus* at 30 DAS. However, minimum tillage (T₅) also had higher proportion of *Cyperus rotundus* with comparable proportion of *Cynodon dactylon* (16.60%) and *Trianthema portulacastrum* (14.75%) at 30 DAS in maize. In case of weed management methods, unweeded control (W₄) recorded higher proportion of dominant grass, *Cynodon dactylon* (27.15%) closely followed by *Cyperus rotundus* (17.33%) at 30 DAS. Whereas, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W₂) recorded higher (37.00%) proportion of *Cyperus rotundus*. However, both hand weeding twice (W₁) and mechanical weeding twice (W₃) registered higher proportion of *Cyperus rotundus* with a relative density of 21.44% and 22.99%, respectively at 30 DAS. *Trianthema portulacastrum* was the next predominant broad leaved weed recorded both with hand weeding twice (W₁) (15.16%) and mechanical weeding twice (W₃) (15.39%) at 30 DAS in maize.

60 DAS : Mould board ploughing followed by cultivator tillage twice (T₃) or disc ploughing followed by cultivator tillage (T₄) recorded the higher proportion of *Cyperus rotundus* registering a relative density of 19.77% and 19.45% respectively at 60 DAS (Table 30). *Trianthema portulacastrum* was the dominant broad-leaved weed which was higher in proportion (18.55% and 17.50%) both in cultivator tillage twice (T₂) and country plough tillage twice (T₁). *Cynodon dactylon* was the predominant grass which was recorded with disc ploughing followed by cultivator tillage twice (T₄) (16.50%) closely followed by mould board ploughing combined with cultivator tillage (T₃) with a relative density of 16.07% at 60 DAS. Among the weed management methods, unweeded control (W₄) registered higher proportion (18.12%) of *Cynodon dactylon*. Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS resulted in higher relative density (17.25%) of *Cyperus rotundus*. *Trianthema portulacastrum* was in higher proportion recording a relative density of 17.18% with hand weeding twice (W₁) followed by 16.34% with mechanical weeding twice (W₃) at 60 DAS in maize.

Harvest : Higher proportion of *Cyperus rotundus* (22.00 and 20.45%) with both mould board ploughing (T₃) and disc ploughing (T₄) followed by cultivator tillage twice *Cynodon dactylon* (13.37% and 13.03%) was next in the order of dominance among grasses

Table 30. Relative density (%) of individual weeds as influenced by preparatory tillage and weed management methods in maize at 60 DAS

Treatments	CD	DE	OG	CR	PH	TP	DA	OBLW
T ₁	10.63	4.93	3.41	13.66	10.09	17.50	12.79	22.14
T ₂	9.35	4.34	3.00	11.90	10.70	18.55	13.55	28.55
T ₃	16.07	7.46	5.16	19.77	7.72	13.38	9.78	20.59
T ₄	16.50	7.66	5.30	19.45	7.65	13.27	9.69	20.42
T ₅	12.86	5.96	4.13	13.08	9.58	16.61	12.14	25.56
W ₁	10.94	5.08	3.51	14.34	9.91	17.18	12.55	26.43
W ₂	11.12	5.16	3.56	17.25	9.42	16.34	11.94	25.14
W ₃	12.14	5.63	3.90	15.42	9.42	16.34	11.95	25.14
W ₄	18.12	8.41	5.82	15.29	7.84	13.60	9.94	17.10

Table 31. Relative density (%) of individual weeds as influenced by preparatory tillage and weed management methods in maize at harvest

Treatments	CD	DE	OG	CR	PH	TP	DA	OBLW
T ₁	9.49	4.41	3.05	14.00	10.35	17.94	13.11	27.61
T ₂	8.90	4.13	2.85	14.75	10.39	18.02	13.46	27.73
T ₃	13.03	6.05	4.18	22.00	8.20	15.98	10.38	21.87
T ₄	13.37	6.20	4.29	20.45	8.34	14.46	10.57	21.68
T ₅	10.84	5.03	3.48	13.23	10.10	17.51	12.80	26.95
W ₁	9.79	4.54	3.14	15.72	10.01	18.77	12.68	26.71
W ₂	12.24	5.68	3.93	20.24	8.67	15.03	10.98	23.13
W ₃	10.82	5.02	3.47	14.72	9.89	17.14	12.76	26.38
W ₄	11.66	5.41	3.74	16.87	9.34	16.19	11.83	24.46

Data statistically not analysed

CD – *Cynodon dactylon*; DE – *Dactyloctenium aegyptium*; OG – Other grasses;

CR – *Cyperus rotundus*; PH – *Parthenium hysterophorus*; TP – *Trianthema portulacastrum*;

DA – *Digera arvensis*; OBLW – Other broad leaved weeds

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

(Table 31). *Trianthema portulacastrum* was the predominant broad-leaved weed (18.02 and 17.94%) recorded both with cultivator tillage twice (T₂) and country plough tillage twice (T₁) among the tillage methods. Similarly, *Trianthema portulacastrum* was in higher proportion with minimum tillage (T₅) at harvest. Unweeded control (W₄) recorded higher proportion (16.87%) of *Cyperus rotundus* closely followed by *Trianthema portulacastrum* (16.19%) among different weeds. Pre-emergence application of atrazine 0.25 k/ha followed by hand weeding on 40 DAS (W₂) resulted in higher relative density (20.24%) of *Cyperus rotundus*. Hand weeding twice (W₁) was found to record higher proportion of predominant broad-leaved weed *Trianthema portulacastrum* (18.77%) closely followed (17.14%) by mechanical weeding twice (W₃) at harvest in maize.

4.1.7. Relative density of group wise weeds

Sunflower

Relative density of grasses, sedge and broad-leaved weeds varied distinctly with preparatory tillage and weed management methods (Table 32). Higher proportion of grasses (38.15%) was recorded by mould board ploughing followed by cultivator tillage twice (T₃) closely followed (36.61%) by disc ploughing followed by cultivator tillage twice (T₄) at 30 DAS in sunflower. Similarly, sedge population was higher (20.58%) in T₄ among the tillage treatments. Country plough tillage twice (T₁) and cultivator tillage twice (T₂) registered higher relative density (62.00 and 61.15%) of broad-leaved weeds at 30 DAS. Minimum tillage (T₅) also recorded higher proportion (57.28%) of broad-leaved weeds followed by grassy (28.79%) weeds at 30 DAS. Among the weed management methods, unweeded control (W₄) recorded higher proportion of grasses (47.20%), pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha (W₂) recorded higher proportion of sedges (24.37%) and either mechanical weeding twice (W₃) (61.45%) or hand weeding twice (W₁) (61.01%) recorded the higher percentage of broad-leaved weeds at 30 DAS. Similar trend was observed at 60 DAS, but the relative density of grasses and sedge reduced from 30 DAS to 60 DAS, whereas, the broad-leaved weed population increased from 30 DAS to 60 DAS. At harvest stage, either T₃ or T₄ registered higher proportion of grasses (26.48% and 26.38%), the relative density of sedge was more (20.83%) in T₄, country plough tillage twice (T₁) and cultivator tillage twice (T₂) resulted in higher proportion (74.56 and 70.81%) of broad-leaved

Table 32. Effect of preparatory tillage and weed management methods on relative density (%) group wise weeds in sunflower

Treatments	30 DAS			60 DAS			Harvest		
	Grasses	Sedge	BLW	Grasses	Sedge	BLW	Grasses	Sedge	BLW
T ₁	24.82	13.16	62.00	18.46	11.59	69.93	16.40	12.72	70.87
T ₂	25.00	13.83	61.15	17.66	12.35	69.95	14.30	11.12	74.56
T ₃	38.15	16.82	45.01	29.17	17.43	53.42	26.48	17.76	55.75
T ₄	36.61	20.58	42.80	28.82	19.93	51.23	26.38	20.83	52.77
T ₅	28.79	13.86	57.28	21.17	11.71	67.10	20.52	12.45	67.02
W ₁	24.84	14.14	61.01	18.73	12.49	68.74	17.56	12.43	70.00
W ₂	25.90	24.37	49.71	22.88	18.11	59.03	26.56	19.63	53.80
W ₃	24.75	13.75	61.45	20.83	14.68	64.48	19.15	14.63	66.20
W ₄	47.20	10.35	42.43	29.79	13.13	57.06	20.00	13.21	66.78

Table 33. Effect of preparatory tillage and weed management methods on relative density (%) group wise weeds in maize

Treatments	30 DAS			60 DAS			Harvest		
	Grasses	Sedge	BLW	Grasses	Sedge	BLW	Grasses	Sedge	BLW
T ₁	23.69	21.03	62.21	18.99	13.66	67.33	16.99	14.00	68.99
T ₂	24.13	19.81	64.82	16.70	11.90	71.38	15.89	14.75	69.34
T ₃	36.43	31.25	42.46	28.71	19.77	51.50	23.29	22.00	54.70
T ₄	36.87	30.79	40.68	29.48	19.45	51.06	23.89	20.45	55.65
T ₅	29.66	20.58	56.77	22.97	13.08	63.93	19.37	13.23	67.38
W ₁	22.99	21.44	60.09	09.55	14.34	66.10	17.48	15.72	66.79
W ₂	24.29	37.00	52.55	19.86	17.25	62.87	21.90	20.24	57.84
W ₃	24.85	22.99	59.23	21.70	15.42	62.87	19.34	14.72	65.92
W ₄	48.50	17.33	41.67	32.36	15.29	52.33	20.82	16.87	62.30

BLW – Broad leaved weeds
T₁ - T₅ : Preparatory tillages

Data statistically not analysed
W₁ - W₄ : Weed management methods

weeds at harvest. The increasing trend of broad-leaved population was observed with hand weeding twice (W_1) followed (66.78%) by unweeded control (W_4). Pre-emergence application of pendimethalin 0.50 + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the highest proportion of grasses (26.56%) and sedge (19.63%) at harvest.

As the growth stages advanced from 30 DAS, the proportion of both grasses and sedge were reduced, while the broad-leaved weed population increased from 30 DAS to harvest, irrespective of preparatory tillage and weed management methods.

Maize

Distinct variation in grasses, sedge and broad-leaved weeds relative density was observed in maize with preparatory tillage and weed management methods (Table 33). Dominance of grassy weeds was observed with disc ploughing (T_4) and mould board ploughing (T_3) followed by cultivator tillage twice with a relative density of 36.87% and 36.87%, respectively at 30 DAS. Sedge weed population was also recorded in higher proportion both by T_3 and T_4 than in other tillage methods. Country plough tillage twice (T_1) and cultivator tillage twice (T_2) recorded the higher proportion (62.21% and 64.82%, respectively) of broad-leaved weeds. In the case of weed management methods, higher grassy weed population (48.50%) was observed with unweeded control (W_4) at 30 DAS. Pre-emergence application of atrazine 0.25 kg/ha (W_2) resulted in higher sedge weed proportion (37.00%). Both hand weeding twice (W_1) and mechanical weeding twice (W_3) recorded higher proportion of broad-leaved weeds (60.09% and 59.23%) at 30 DAS. Similar trend was observed at 60 DAS for both tillage and weed management methods, but the proportion of grasses and sedge reduced while, broad-leaved weeds relative density increased. At harvest stage, both T_3 and T_4 recorded higher proportion of grasses (26.48% and 26.38%) and T_4 registered higher sedge weed population (20.83%). Broad-leaved weeds were higher in proportion to total weeds with cultivator tillage twice (T_2) (74.56%) followed by country plough tillage twice recording a relative density of 74.56% and 70.87% respectively, at harvest. Among the weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the higher proportion of both

grasses (26.56%) and sedge (19.63%) at harvest. But, the broad-leaved weed proportion was higher (70.00%) in hand weeding twice (W_1) closely followed by both unweeded control (W_4) (66.78%) and mechanical weeding twice (W_3). In maize crop also, as the stages advanced the relative proportion of grasses and sedge was reduced, while the broad-leaved weeds proportion was increased from 30 DAS to harvest stage.

4.1.8. Weed dry matter

Sunflower

Both preparatory tillage and weed management methods significantly influenced the weed dry matter at all the growth stages (Table 34). Both disc ploughing (T_4) and mould board ploughing (T_3) followed by cultivator tillage twice recorded the lowest weed dry matter and were comparable with each other at all the growth stages. Country plough tillage twice (T_1) resulted in the highest weed dry matter and was comparable with that of minimum tillage (T_5) and cultivator tillage twice (T_2) at 30 DAS. At subsequent growth stages, minimum tillage (T_5) registered higher weed dry matter and was comparable with that of country plough tillage twice (T_1) at 60 DAS and at harvest. Cultivator tillage twice (T_2) was found to be superior to T_5 or T_1 in reducing the weed dry matter at subsequent growth stages.

Among the weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the lowest weed dry matter at all the three stages. Whereas, unweeded control (W_4) registered the highest weed dry matter at all the stages of observation. However, the weed dry matter with hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were comparable with each other by recording lesser weed dry matter than with W_4 at all the three stages.

Weed dry matter was not significantly influenced by the interaction effect of preparatory tillage and weed management methods at all the stages in sunflower.

Table 34. Weed dry matter (kg/ha) as influenced by preparatory tillage and weed management methods in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	12.57(182.15)	22.17(574.49)	20.35(482.86)	11.24(149.81)	19.86(474.79)	19.38(447.17)
T ₂	11.23(147.32)	18.27(407.67)	16.34(327.22)	9.89(118.27)	16.20(329.68)	15.47(297.10)
T ₃	8.72(89.46)	14.30(264.84)	13.03(213.71)	7.82(75.45)	12.96(229.02)	12.61(206.61)
T ₄	8.35(83.30)	12.24(197.02)	11.47(168.00)	7.43(69.56)	11.02(168.95)	11.18(163.66)
T ₅	11.94(166.11)	23.92(684.58)	21.98(580.71)	10.95(148.12)	22.34(624.66)	22.06(598.97)
SEd	0.58	1.52	1.39	0.54	1.44	1.39
CD (5%)	1.35	3.52	3.20	1.24	3.32	3.22
W ₁	10.18(118.55)	16.85(340.83)	14.45(249.15)	9.54(104.23)	15.82(300.82)	14.47(250.98)
W ₂	6.86(53.77)	10.73(135.56)	10.81(135.11)	4.79(26.08)	7.87(74.10)	9.35(101.02)
W ₃	10.73(130.10)	17.39(360.66)	15.79(298.70)	9.80(108.60)	15.89(302.45)	15.24(279.67)
W ₄	14.49(233.26)	27.75(865.83)	25.50(735.04)	13.74(210.07)	26.33(784.32)	25.50(739.14)
SEd	0.43	0.98	0.87	0.51	1.05	0.94
CD (5%)	0.88	2.00	1.79	1.04	2.16	1.93
<u>T at W</u> SEd	1.02	2.44	2.19	1.12	2.50	2.31
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	0.97	2.20	1.96	1.14	2.36	2.12
CD (5%)	NS	NS	NS	NS	NS	NS

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Maize

Significant variation was observed both by preparatory tillage and weed management methods in influencing the weed dry matter in maize (Table 34). Lower weed dry matter was recorded with disc ploughing followed by cultivator tillage twice (T_4), which was comparable with that of mould board ploughing followed by cultivator tillage (T_3) at all the stages of observation. Minimum tillage (T_5) resulted in the highest weed dry matter at all stages but was on par with that of cultivator tillage (T_2) or country plough tillage (T_1) twice at 30 DAS. Whereas, the weed dry matter with T_5 was on par with that of T_1 only at 60 DAS and at harvest. Similarly, T_2 and T_3 registered lower weed dry matter than T_5 , but were comparable with each other at later growth stages.

In case of weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) registered the lowest weed dry matter, while unweeded control (W_4) recorded the highest weed dry matter at all the stages of observation. Higher weed dry matter registered with either hand weeding twice (W_1) or mechanical weeding twice (W_3) on 20 and 40 DAS than with W_2 , were comparable with each other at all the growth stages.

Interaction effect between preparatory tillage and weed management methods was not significant in altering the weed dry matter at any of the growth stages.

4.2. STUDIES ON PLANT CHARACTERS

4.2.1. Plant height

Sunflower

Plant height was significantly influenced by preparatory tillage and weed management methods (Table 35). Disc ploughing followed by cultivator tillage (T_4) recorded taller plants than with other tillage methods at all the stages. However, the plant height with T_4 was comparable with that of mould board ploughing followed by cultivator tillage twice (T_3) at all the stages and that of cultivator tillage twice (T_2) at 30 DAS and at harvest. Shorter plants were recorded with minimum tillage (T_5), which was on par with that of both country plough tillage twice (T_1) at all the stages and cultivator

Table 35. Plant height (cm) as influenced by preparatory tillage and weed management methods in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	42.87	139.31	147.76	57.19	124.46	195.48
T ₂	46.21	144.09	153.31	60.01	128.87	198.09
T ₃	47.67	147.46	162.28	63.08	134.61	200.82
T ₄	49.60	155.67	161.26	66.24	139.52	206.78
T ₅	39.41	134.97	139.19	52.97	119.22	187.60
SEd	2.06	4.04	4.91	2.62	4.09	3.59
CD (5%)	4.75	9.31	11.34	6.04	9.44	8.29
W ₁	46.11	140.22	150.58	63.41	133.04	202.23
W ₂	51.92	157.67	169.42	70.57	142.51	218.35
W ₃	45.30	142.33	155.88	62.88	129.71	194.38
W ₄	37.27	136.89	138.16	42.72	112.09	176.05
SEd	1.40	2.15	3.34	2.76	2.93	4.04
CD (5%)	2.87	4.40	6.82	5.64	5.98	8.25
<u>T at W</u> SEd	3.41	5.81	8.12	5.96	7.00	8.61
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	3.14	4.82	7.46	6.18	6.55	9.03
CD (5%)	NS	NS	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

tillage twice (T_2) at 60 DAS alone. Comparable plant height was recorded between T_1 and T_2 at all the three stages of observation.

Among the weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) resulted in higher plant height than other weed management methods. However, shorter plants were observed with hand weeding twice (W_1) and mechanical weeding twice (W_3) resulted with shorter plants than in W_2 , but were taller than W_4 at all the three stages. Plant height with W_1 was comparable with that of W_4 at 60 DAS.

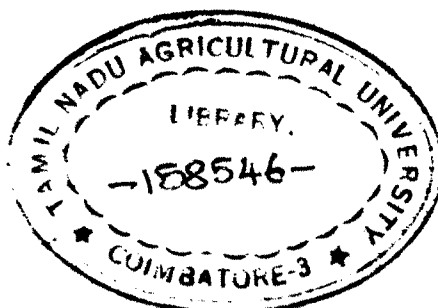
Plant height was not significantly influenced by the interaction effect between preparatory tillage and weed management methods.

Maize

Both preparatory tillage and weed management methods significantly influenced the plant height at all the growth stages (Table 35). Maize plants were taller with disc ploughing followed by cultivator tillage twice (T_4) than with other tillage methods, but were on par with that of mould board ploughing followed by cultivator tillage (T_3) at all the growth stages. Minimum tillage (T_5) resulted in shorter plants, but was comparable with that of country plough tillage twice (T_1). However, the plant height with country plough tillage twice (T_1) was comparable with that of cultivator tillage twice (T_2) at all the growth stages.

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the highest plant height than other weed management methods. The plants were shorter with unweeded control (W_4) at all the growth stages. Hand weeding twice (W_1) or mechanical weeding twice (W_3) resulted in shorter plants than W_2 , but were on par with each other in influencing the plant height at all the growth stages.

The interaction effect between preparatory tillage and weed management methods was not significant in altering the plant height at any growth stage.



4.2.1.2. Plant dry matter production

Sunflower

Dry matter production (DMP) was significantly influenced both by preparatory tillage and weed management methods (Table 36). Preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) recorded higher DMP than other preparatory tillage methods. However, T_4 was on par with that of mould board ploughing + cultivator tillage (T_3) and cultivator tillage twice (T_2) at 30 DAS and both T_4 and T_3 were comparable with each other at 60 DAS as well as at harvest. Minimum tillage (T_5) resulted in the lowest DMP, which was similar to that of either country plough tillage twice (T_1) or cultivator tillage twice (T_2) at all the growth stages.

Higher dry matter production was recorded with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) than other weed management methods at all the growth stages. Unweeded control (W_4) recorded the lowest DMP at all the growth stages. However, the highest DMP with W_2 was comparable with that of both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS at 30 DAS. But, W_1 and W_3 were significantly different from W_2 and were comparable with each other at 60 DAS and at harvest.

Dry matter production was not affected significantly by the interaction effect between preparatory tillage and weed management methods.

Maize

Both preparatory tillage and weed management methods significantly influenced the dry matter production (DMP) at all the stages (Table 36). Either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice resulted in the higher DMP than other tillages, but were on par with each other at all the stages. Lowest DMP was recorded with minimum tillage (T_5) which was on par with both cultivator tillage twice (T_2) and country plough tillage twice (T_1) at 30, 60 DAS and at harvest. However, T_2 and T_4 were comparable with each other but were superior to T_5 at 30 DAS.

Table 36. Plant dry matter production (kg/ha) as influenced by preparatory tillage and weed management methods in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	746	5622	6981	544	4533	7911
T ₂	777	5911	7201	579	4672	7820
T ₃	805	6668	7988	645	5385	8788
T ₄	817	6780	8061	628	5408	8569
T ₅	739	5446	6721	517	4322	7747
SEd	18	309	307	28	256	243
CD (5%)	41	714	709	64	590	560
W ₁	801	6464	7741	601	5605	8990
W ₂	837	7429	8739	658	5922	9494
W ₃	805	6507	7776	587	5598	8790
W ₄	664	3940	5306	483	2331	5394
SEd	18	345	337	17	388	432
CD (5%)	36	705	689	35	794	883
<u>T at W</u> SEd	38	736	722	44	795	872
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	39	772	754	39	869	967
CD (5%)	NS	NS	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the highest DMP, while unweeded control (W_4) resulted in the lowest DMP at all the stages. The highest DMP with W_2 was comparable with both hand weeding twice (W_1) and mechanical weeding twice (W_3) at 60 DAS as well as at harvest, but both W_1 and W_3 were significantly different from W_2 in recording lower dry matter production and were on par with each other at 30 DAS.

There was no significant interaction effect between preparatory tillage and weed management methods influencing plant DMP.

4.2.2. Physiological parameters

4.2.2.1. Leaf area index

Sunflower

Both preparatory tillage and weed management methods significantly altered the leaf area index (LAI) (Table 37). Either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice resulted in higher LAI than other tillage methods. Whereas, minimum tillage (T_5) recorded lower LAI at all the three stages. However, the lowest LAI with T_5 was on par with both cultivator tillage twice (T_2) and country plough tillage twice (T_1) at 30 and 60 DAS and with country plough tillage twice (T_1) alone at harvest. Comparable LAI was recorded with T_2 and T_3 at 30 DAS and similarly country plough tillage twice (T_1) and cultivator tillage twice (T_2) as well as T_3 were on par with each other in recording LAI at harvest.

Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) recorded the highest LAI at all the growth stages. The LAI was the lowest with unweeded control (W_4) at all the stages. However, the higher LAI with herbicidal + manual weeding (W_2) was comparable with that of both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS at all the three growth stages.

The interaction effect between preparatory tillage and weed management methods was not significant in influencing the LAI at any of the stages.

Table 37. Effect of preparatory tillage and weed management methods on LAI in sunflower-maize cropping

Treatments	Sunflower			Maize		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T ₁	0.59	4.06	2.48	0.71	3.98	2.99
T ₂	0.60	4.11	2.52	0.74	4.06	3.03
T ₃	0.63	4.22	2.55	0.80	4.16	3.12
T ₄	0.64	4.27	2.60	0.83	4.22	3.18
T ₅	0.58	4.10	2.43	0.70	3.91	2.92
SEd	0.01	0.04	0.03	0.02	0.06	0.05
CD (5%)	0.03	0.10	0.80	0.06	0.14	0.12
W ₁	0.65	4.42	2.76	0.86	4.60	3.67
W ₂	0.67	4.52	2.92	0.90	4.70	3.76
W ₃	0.64	4.02	2.74	0.85	4.58	3.64
W ₄	0.48	3.27	1.65	0.42	2.38	1.12
SEd	0.01	0.13	0.13	0.05	0.25	0.29
CD (5%)	0.04	0.27	0.27	0.10	0.52	0.59
<u>T at W</u> SEd	0.04	0.26	0.26	0.10	0.50	0.57
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	0.04	0.30	0.29	0.11	0.57	0.65
CD (5%)	NS	NS	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Significant influence was observed on leaf area index (LAI) both by preparatory tillage and weed management methods (Table 37). Higher LAI was recorded with disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice than other tillage methods at all the growth stages. Minimum tillage (T_5) resulted in the lowest LAI. However, LAI with T_5 was on par with that of cultivator tillage twice (T_2) and country plough tillage twice (T_1) at 30 DAS and at harvest, while T_5 and T_1 were on par with each other at 60 DAS. Comparable LAI was observed between T_2 and T_3 at all the stages of observation.

Highest LAI was recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) at all the stages and the LAI was the lowest with unweeded control (W_4). However, the highest LAI with W_2 was comparable with that of either hand weeding twice (W_1) or mechanical weeding twice (W_3) on 20 and 40 DAS at all the three stages.

Significant variation was not observed in LAI by the interaction effect between preparatory tillage and weed management methods at any growth stage.

4.2.2.2. Growth analysis

Sunflower

Growth analysis was made in terms of crop growth rate (CGR) relative growth rate (RGR) and net assimilation rate (NAR) as influenced by preparatory tillage and weed management methods at different growth stages in sunflower and maize.

Crop growth rate (CGR) was higher in disc ploughing followed by cultivator tillage twice (T_4) up to 30 DAS and in mould board ploughing followed cultivator tillage twice (T_3) between 30 and 60 DAS and up to harvest stages (Table 38). Lowest CGR was recorded by minimum tillage (T_5), which was closely followed by country plough tillage twice (T_1) at 30 DAS. Between 30 and 60 DAS the lowest CGR was observed with T_1 and from 60 DAS to harvest, T_5 recorded the lowest CGR.

Table 38. Effect of preparatory tillage and weed management methods on crop growth, relative growth and net assimilation rate in sunflower

Treatment	Crop growth rate (g/m ² /day)			Relative growth rate (g/g/day)			Net assimilation rate (mg/cm ² /day)	
	0 -30 DAS	30 -60 DAS	60 - 105 DAS	0 -30 DAS	30 -60 DAS	60 - 105 DAS	30 - 60 DAS	60 - 105 DAS
T ₁	2.48	16.24	4.52	0.0095	0.0280	0.0033	6.03	2.92
T ₂	2.59	17.11	4.29	0.0096	0.0280	0.0029	6.51	2.92
T ₃	2.68	19.95	4.39	0.0096	0.0330	0.0027	7.86	3.14
T ₄	2.72	19.87	4.26	0.0097	0.0290	0.0026	7.91	2.91
T ₅	2.46	18.18	4.24	0.0095	0.0280	0.0032	6.77	2.77
W ₁	2.66	18.87	4.25	0.0096	0.0290	0.0026	7.71	3.17
W ₂	2.78	21.97	4.36	0.0097	0.0310	0.0023	9.28	3.30
W ₃	2.68	19.34	4.22	0.0096	0.0320	0.0026	7.44	3.03
W ₄	2.21	12.91	4.52	0.0094	0.0250	0.0043	3.10	2.27

Data statistically not analysed

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Among the weed management methods, the highest CGR was recorded with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha (W₂) up to 30 DAS and between 30 and 60 DAS. Whereas, the lowest CGR was recorded with unweeded control (W₄) from 60 DAS to harvest stage.

Relative growth rate (RGR) did not vary much with both preparatory tillage and weed management methods. However, disc ploughing followed by cultivator tillage (T₄) registered higher RGR up to 30 DAS, mould board ploughing followed by cultivator tillage (T₃) between 30 and 60 DAS and country plough tillage twice (T₁) recorded higher RGR from 60 DAS to harvest stage.

In case of weed management methods, pre-emergence application of pendimethalin 0.50kg/ha + metolachlor 0.50 kg/ha (W₂) recorded higher RGR up to 30 DAS, mechanical weeding twice (W₃) recorded higher RGR between 30 and 60 DAS and unweeded control (W₄) registered higher RGR at harvest.

Net assimilation rate (NAR) was higher with disc ploughing followed by cultivator tillage (T₄), which was closely followed by mould board ploughing combined with cultivator tillage (T₃) between 30 and 60 DAS. Minimum tillage (T₅) recorded lower NAR between 30 and 60 DAS as well as 60 and 90 DAS. Whereas, higher NAR was recorded with T₃ which was followed by either with cultivator tillage twice (T₂) or country plough tillage twice (T₁) between 60 and 90 DAS. Comparable NAR was also recorded with T₁, T₂ and T₄ between 60 and 90 DAS.

In the case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂) registered higher NAR, while unweeded control (W₄) recorded lower NAR between 30 and 60 DAS as well as 60 and 90 DAS.

Maize

Crop growth rate (CGR) was higher with mould board ploughing followed by cultivator tillage (T₃) up to 30 DAS and between 30 DAS and harvest stages (Table 39).

Table 39. Effect of preparatory tillage and weed management methods on crop growth, relative growth and net assimilation rate in maize

Treatment	Crop growth rate (g/m ² /day)			Relative growth rate (g/g/day)			Net assimilation rate (mg/cm ² /day)	
	0-30 DAS	30-60 DAS	60-105 DAS	0-30 DAS	30-60 DAS	60-105 DAS	30-60 DAS	60-105 DAS
T ₁	1.84	13.29	7.50	0.0091	0.0295	0.0057	7.04	7.42
T ₂	1.92	13.76	6.87	0.0092	0.0290	0.0053	7.40	7.17
T ₃	2.15	15.79	7.55	0.0093	0.0293	0.0051	8.96	7.85
T ₄	2.09	15.93	7.02	0.0093	0.0298	0.0048	9.12	7.30
T ₅	1.72	12.68	7.61	0.0090	0.0293	0.0060	6.51	6.95
W ₁	2.00	16.67	7.51	0.0092	0.0316	0.0026	10.00	8.38
W ₂	2.19	17.64	7.93	0.0093	0.0312	0.0060	11.17	8.94
W ₃	1.95	16.70	7.09	0.0092	0.0320	0.0045	10.10	7.99
W ₄	1.61	6.15	6.79	0.0089	0.0226	0.0045	1.92	3.11

Data statistically not analysed

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Whereas, disc ploughing followed by cultivator tillage twice (T_4) recorded higher CGR between 30 and 60 DAS. Minimum tillage (T_5) resulted in the lowest CGR values up to 30 DAS and between 30 and 60 DAS. But, T_4 recorded the lowest CGR value at harvest.

Higher CGR was recorded by pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) at all the stages while, unweeded control (W_4) registered the lowest CGR value at 30, 60 DAS as well as at harvest.

There was no much variation in RGR values among the preparatory tillage and weed management methods. In general, mould board ploughing (T_3) and disc ploughing (T_4) followed by cultivator tillage twice recorded higher RGR values up to 30 DAS and T_4 alone between 30 and 60 DAS. Minimum tillage (T_5) resulted in higher RGR value at harvest.

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) recorded higher RGR up to 30 DAS and between 60 DAS and harvest. Mechanical weeding twice (W_3) recorded higher RGR between 30 and 60 DAS. Unweeded control (W_4) resulted in lower RGR values up to 30 DAS and between 30 and 60 DAS. Lower RGR value was recorded with manual weeding twice (W_1) at harvest.

Higher net assimilation rate (NAR) was recorded with disc ploughing followed by cultivator tillage (T_4) between 30 and 60 DAS, which was followed by mould board ploughing combined with cultivator tillage (T_3). Minimum tillage (T_5) recorded lower NAR between 30 and 60 DAS as well as 60 DAS and harvest (105 DAS). Mould board ploughing combined with cultivator tillage (T_3) registered higher NAR, which was followed by country plough tillage twice (T_1) and disc ploughing, followed by cultivator tillage twice (T_4) between 60 DAS and harvest.

Among the weed management methods, higher NAR was recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) between 30 and 60 DAS as well as 60 DAS and harvest. Lower NAR was recorded with unweeded control (W_4) both between 30 and 60 DAS and 60 DAS and harvest stages.

4.2.3. Yield attributes

Sunflower

Both preparatory tillage and weed management methods significantly influenced the yield attributing components of sunflower (Table 40). Preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) recorded the highest capitulum diameter, weight of the capitulum with more number of seeds per capitulum and test weight which were on par with that of mould board ploughing combined with cultivator tillage (T_3). However, higher weight of the capitulum and more seeds per capitulum with T_4 and T_3 were comparable with that of cultivator tillage twice (T_2). Minimum tillage (T_5) resulted in the lowest values of the yield attributing components, which was on par with that of country plough tillage twice (T_1). All the yield attributing components recorded with T_1 , T_2 and T_3 were significantly superior to that of minimum tillage (T_5).

Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) resulted in the highest capitulum diameter, weight of capitulum, number of seeds per capitulum and test weight while unweeded control (W_4) recorded the lowest values. However, W_2 was on par with hand weeding twice (W_1) in influencing the capitulum diameter, weight of the capitulum and test weight, while W_2 was comparable with that of both W_1 and mechanical weeding twice (W_3) in the case of number of seeds per capitulum.

Yield attributes were not significantly influenced by the interaction effect between preparatory tillage and weed management methods.

Maize

Significant variation was observed on yield attributes as influenced both by preparatory tillage and weed management methods (Table 41). Either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice recorded the highest values of all yield attributing components viz., cob length, cob girth, weight of the cob, number of grains per cob and test weight. Minimum tillage (T_5) registered the lowest values of all yield attributes. However, T_5 was comparable with country plough tillage twice (T_1) in influencing

Table 40. Effect of preparatory tillage and weed management methods on yield attributes of sunflower

Treatments	Capitulum diameter (cm)	Capitulum weight (g)	No. of seeds / Capitulum	Test weight (g)
T ₁	12.72	47.48	967	38.80
T ₂	13.55	50.05	979	40.25
T ₃	14.05	51.74	999	41.05
T ₄	15.62	55.83	1003	43.85
T ₅	11.35	42.63	943	36.95
SEd	0.80	2.50	12	1.31
CD (5%)	1.86	5.77	28	3.03
W ₁	14.38	53.93	1014	44.16
W ₂	14.86	55.71	1023	45.60
W ₃	13.44	50.65	1009	39.78
W ₄	11.16	37.88	861	31.38
SEd	0.38	1.86	18	1.47
CD (5%)	0.77	3.81	36	3.00
<u>T at W</u> SEd	1.09	4.40	36	3.14
CD (5%)	NS	NS	NS	NS
<u>W at T</u> SEd	0.85	4.17	40	3.29
CD (5%)	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Table 41. Effect of preparatory tillage and weed management methods on yield attributes of maize

Treatments	Cob length (cm)	Cob girth (cm)	No. of grains / cob	Cob weight (g)	Test weight (g)
T ₁	14.42	11.60	357	57.25	275
T ₂	15.92	12.35	371	59.50	283
T ₃	16.65	13.20	398	63.77	288
T ₄	18.00	14.80	418	63.05	299
T ₅	13.37	11.07	348	55.80	268
SEd	0.92	0.74	15	2.37	6.00
CD (5%)	2.14	1.72	34	5.48	14.00
W ₁	16.58	12.82	422	67.74	296
W ₂	17.82	14.10	436	69.86	317
W ₃	16.48	12.80	417	66.96	292
W ₄	11.82	10.70	237	38.14	225
SEd	0.61	0.34	22	3.44	9.00
CD (5%)	1.25	0.69	44	7.03	19.00
<u>T at W</u> SEd	1.51	0.99	44	7.08	19.00
CD (5%)	NS	NS	NS	NS	NS
<u>W at T</u> SEd	1.27	0.76	48	7.07	20
CD (5%)	NS	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

the cob length and test weight, while T_5 was on par with both T_1 and cultivator tillage twice (T_2) in altering the cob girth, weight of the cob and number of grains per cob.

Higher cob length, cob girth and more weight of individual cob, number of grains per cob and test weight were recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2). Unweeded control (W_4) recorded the lowest values of all the yield attributes. However, the highest values with W_2 were comparable with that of both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS in changing the weight of the cob and number of grains per cob, while W_2 was on par with W_1 alone in influencing the cob length.

Significant interaction effect was not found between preparatory tillage and weed management methods in influencing the yield attributes.

4.2.4. Yield

Sunflower

Preparatory tillage and weed management methods significantly influenced the seed yield of sunflower (Table 42). Preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) recorded higher seed yield (1365 kg/ha). However, the seed yield (1315 kg/ha) recorded with mould board ploughing followed by cultivator tillage twice (T_4) was comparable with that of T_3 . Similarly, cultivator tillage twice (T_2) registered higher seed yield than T_4 , but was on par with that of T_3 . Minimum tillage (T_5) resulted in the lowest seed yield. But, the lowest seed yield in T_5 was on par with both cultivator tillage twice (T_2) and country plough tillage twice (T_1).

Among the weed management methods, higher seed yield of 1511 kg/ha was recorded with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2). Unweeded control (W_4) resulted in the lowest yield (923 kg/ha). Comparable seed yield was recorded both with hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS, which were significantly superior to unweeded control (W_4), but were lesser than with W_2 .

Table 42. Effect of preparatory tillage and weed management methods on seed yield of sunflower and grain and stover yields of maize

Treatments	Sunflower	Maize	
	Seed yield (kg/ha)	Grain yield (kg/ha)	Stover yield (kg/ha)
T ₁	1241	4458	8222
T ₂	1283	4611	8421
T ₃	1314	4679	8796
T ₄	1365	4829	9032
T ₅	1215	4372	7794
SEd	30.00	92	247
CD (5%)	70.00	212	570
W ₁	1357	4948	8887
W ₂	1511	5348	9800
W ₃	1343	4917	8615
W ₄	923	3146	6511
SEd	58.00	224	322
CD (5%)	70.00	459	659
<u>T at W</u> SEd	116	445	672
CD (5%)	NS	NS	NS
<u>W at T</u> SEd	130	502	721
CD (5%)	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

There was no significant interaction effect between preparatory tillage and weed management methods on the seed yield.

Maize

Both grain and stover yields were significantly influenced by preparatory tillage and weed management methods (Table 42). Higher grain (4829 kg/ha) and stover (9032 kg/ha) yields were recorded with mould board ploughing followed by cultivator tillage (T_3) and were on par with disc ploughing followed by cultivator tillage twice (T_4). Minimum tillage (T_5) registered the lowest grain (4372 kg/ha) as well as stover (7794 kg/ha) yields. The lowest grain and stover yields with T_5 were comparable with that of country plough tillage twice (T_1). Comparable yields of grain and stover were recorded with the country plough tillage (T_1) and cultivator tillage (T_2). Similarly, T_2 and T_3 recorded comparable grain and stover yields.

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) registered higher grain (5348 kg/ha) and stover (9800 kg/ha) yields. Whereas, unweeded control (W_4) recorded the lowest grain (3146 kg/ha) and stover (6511 kg/ha) yields. The highest grain yield with W_2 was on par with both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS. However, W_1 and W_3 were on par and significantly varied from W_2 and W_4 in influencing the stover yield.

Neither grain yield nor stover yield was significantly influenced by the interaction effect of preparatory tillage and weed management methods.

4.3. NUTRIENT ANALYSIS

4.3.1. Nutrient uptake by crops

Sunflower

Significant variation was observed on the nutrient uptake by crops with preparatory tillage and weed management methods (Table 43). Both disc ploughing (T_4) and mould board ploughing (T_3) followed by cultivator tillage twice recorded higher uptake of Nitrogen (N), Phosphorus (P) and Potassium (K) and lowest uptake of N, P and K were recorded by

Table 43. Nutrient uptake by plants (kg/ha) as influenced by preparatory tillage and weed management methods in sunflower-maize cropping

Treatments	Sunflower			Maize		
	N	P	K	N	P	K
T ₁	57.09	11.90	40.32	95.28	19.77	91.18
T ₂	58.89	12.26	41.58	94.18	19.53	90.13
T ₃	65.32	13.60	46.13	105.82	21.95	101.29
T ₄	65.92	13.72	46.55	103.21	21.41	98.75
T ₅	54.97	11.46	38.84	93.31	19.34	89.30
SEd	2.51	0.51	1.77	2.92	0.60	2.80
CD (5%)	5.80	1.19	4.09	6.74	1.40	6.45
W ₁	63.46	13.15	44.89	107.88	22.47	103.38
W ₂	72.00	15.72	51.55	116.77	24.68	110.12
W ₃	63.31	12.99	44.32	104.60	21.53	101.53
W ₄	42.97	8.48	29.97	64.18	12.92	61.49
SEd	2.83	0.69	2.09	5.39	1.18	5.09
CD (5%)	5.79	1.41	4.27	11.01	2.42	10.41
<u>T at W</u> SEd	6.04	1.43	4.42	10.84	2.38	10.26
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	6.34	1.54	4.67	12.05	2.65	11.40
CD (5%)	NS	NS	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

minimum tillage (T_5) which was on par with either cultivator tillage twice (T_2) or country plough tillage twice (T_1).

Pre-emergence application of pendimethalin 0.5 kg/ha + metolachlor 0.50 kg/ha followed by land weeding on 40 DAS (W_2) registered higher uptake of N, P and K while unweeded control (W_4) resulted in the lowest uptake. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) were on par with each other and significantly superior to W_4 in reducing uptake of N, P and K by the plants.

Interaction effect between preparatory tillage and weed management methods was not significant in influencing the N, P and K uptake by sunflower plants.

Maize

Preparatory tillage and weed management methods significantly influenced the N, P and K nutrients uptake by the plants (Table 43). Mould board ploughing followed by cultivator tillage twice (T_3) recorded higher uptake of nitrogen and it was comparable with that of disc ploughing followed by cultivator tillage (T_4). Similar trend of P and K uptake was observed with T_3 and T_4 . Minimum tillage resulted (T_5) in lower nutrient uptake than with other tillage methods. However, the lowest N, P and K uptake in T_5 , which were on par with both cultivator tillage twice (T_1) and country plough tillage twice (T_2).

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) resulted in the highest N, P and K uptake, which were on par with hand weeding twice (W_1). Lower uptake of nutrients were recorded by unweeded control (W_4). Both manual weeding twice (W_1) and mechanical weeding twice (W_3) were comparable with each other in influencing the uptake of N, P and K by the plants.

Uptake of N, P and K by the maize plants were not significantly influenced by the interaction effect between preparatory tillage and weed management methods.

4.3.2. Nutrient removal by weeds

Sunflower

4.3.2.1. Nitrogen

Significant influence was found both by preparatory tillage and weed management methods on nutrient removal by weeds (Table 44). Preparatory tillage with disc ploughing followed by cultivator tillage twice (T₄) resulted in lower nitrogen (N) removal by weeds. However, the lowest N removal with T₄ was comparable with that of mould board ploughing followed by cultivator tillage twice (T₃). The highest N removal was recorded with minimum tillage (T₅), which was comparable with that of country plough tillage twice (T₁) and cultivator tillage twice (T₂).

Among weed management methods, the lowest N removal was registered with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding at 40 DAS (W₂), while unweeded control (W₄) recorded the highest N removal by weeds. Both hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS were significantly superior to W₄ by registering lesser N removal by weeds and were comparable with each other in reducing the N removal by weeds.

Removal of N by weeds was not significantly influenced by the interaction effect between preparatory tillage and weed management methods.

4.3.2.2. Phosphorus

Phosphorus (P) removal by weeds was found to be significantly influenced both by preparatory tillage and weed management methods (Table 44). Disc ploughing followed by cultivator tillage twice (T₄) registered the lowest removal of P by weeds. However it was on par with both mould board ploughing followed by cultivator tillage twice (T₃) and cultivator tillage twice (T₂) in recording lower P removal by weeds. Minimum tillage (T₅) recorded the highest P removal by weeds and was comparable with country ploughing twice (T₁). Both country plough tillage (T₁) and cultivator tillage (T₂) were on par with each other in removal of P by weeds.

Table 44. Nutrient removal by weeds (kg/ha) as influenced by preparatory tillage and weed management methods in sunflower-maize cropping

Treatments	Sunflower			Maize		
	N	P	K	N	P	K
T ₁	22.60	7.14	17.93	21.02	7.26	19.37
T ₂	21.67	6.33	16.06	18.17	6.21	13.48
T ₃	17.22	5.18	15.15	15.80	5.15	14.63
T ₄	16.15	4.97	14.47	14.30	4.49	10.95
T ₅	24.57	8.02	19.26	24.70	8.37	23.12
SEd	1.83	0.65	1.01	2.12	0.79	2.48
CD (5%)	4.24	1.52	2.33	4.89	1.84	5.73
W ₁	18.36	5.31	15.51	17.26	5.30	13.64
W ₂	14.90	4.55	10.16	13.28	3.81	13.16
W ₃	18.96	5.19	4.87	17.74	5.50	15.52
W ₄	29.56	10.26	25.76	26.92	10.58	22.91
SEd	1.50	0.60	1.50	1.36	0.68	1.24
CD (5%)	3.08	1.24	3.08	2.78	1.39	2.53
<u>T at W</u> SEd	3.45	1.34	3.09	3.38	1.54	3.45
CD (5%)	NS	NS	NS	NS	NS	NS
<u>W at T</u> SEd	3.37	1.35	3.37	3.05	1.52	2.77
CD (5%)	NS	NS	NS	NS	NS	NS

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

In case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) resulted in lower P removal by weeds. While, higher P removal by weeds was recorded with unweeded control (W_4). However, the lowest P removal with W_2 was comparable with that of either hand weeding twice (W_1) or mechanical weeding twice (W_3) on 20 and 40 DAS.

There was no significant interaction effect between preparatory tillage and weed management methods on P removal by weeds.

4.3.2.3. Potassium

Preparatory tillage and weed management methods significantly influenced potassium (K) removal by weeds (Table 44). Disc ploughing followed by cultivator tillage twice (T_4) recorded the lowest K removal by weeds and was on par with that of mould board ploughing followed by cultivator tillage twice (T_3) and cultivator tillage twice (T_2). Minimum tillage (T_5) registered the highest removal of K by the weeds, which was on par with country plough tillage twice (T_1). Similarly, T_1 and T_2 were comparable with each other.

Among the weed management methods, lower removal of K by weeds was recorded with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2). While unweeded control (W_4) recorded the highest K removal. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were found to be significantly superior and on par with each other in reducing the K removal by the weeds.

The interaction effect between preparatory tillage and weed management methods did not significantly influence the K removal by the weeds.

Maize

4.3.2.4. Nitrogen

Nitrogen (N) removal by weeds was significantly influenced both by preparatory tillage and weed management methods (Table 44). Disc ploughing followed by cultivator tillage twice (T_4) recorded the lowest N removal by weeds which were comparable with that

of mould board ploughing followed by cultivator tillage twice (T_3) and country ploughing twice (T_1). Minimum tillage (T_5) recorded the highest N removal by weeds, which was found to be on par with country plough tillage twice (T_1). Both T_1 and T_2 were also on par with each other in removing N by the weeds.

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding (W_2) resulted in the lowest N removal by weeds and unweeded control (W_4) recorded the highest N removal. Either hand weeding twice (W_1) or mechanical weeding twice (W_3) on 20 and 40 DAS was significantly superior to W_4 or both were on par with each other in reducing the N removal by the weeds.

No significant interaction effect was observed between preparatory tillage and weed management methods in reducing the N removal by the weeds.

4.3.2.5. Phosphorus

Phosphorus (P) removal by weeds was in similar trend as that of N removal by weeds (Table 44). Disc ploughing followed by cultivator tillage twice (T_4) recorded the lowest P removal which was on par with both mould board ploughing followed by cultivator tillage twice (T_3) and country plough tillage twice (T_1). Highest removal of P by weeds was recorded with minimum tillage (T_5), which was on par with country plough tillage (T_1). Cultivator tillage twice (T_2) was comparable with T_1 in influencing the P removal by the weeds.

Pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) registered the lowest P removal by weeds, whereas the highest P removal was recorded by unweeded control (W_4). Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were found to be significantly better than W_4 in reducing the P removal by weeds, which were on par with each other.

Interaction effect between preparatory tillage and weed management methods was not significant in influencing the P removal by the weeds.

4.3.2.6. Potassium

Both preparatory tillage and weed management methods influenced the potassium removal by the weeds significantly (Table 44). Disc ploughing followed by cultivator tillage twice (T₄) recorded the lowest K removal, whereas minimum tillage (T₅) resulted in higher removal of K by the weeds. However, lower K removal with T₄ was comparable with both mould board ploughing followed by cultivator tillage twice (T₃) and country plough tillage twice (T₁). Highest K removal with T₅ was on par with that of T₁ and cultivator tillage twice (T₂).

Lower K removal by weeds was recorded with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding at 40 DAS (W₂). Whereas, unweeded control (W₄) registered higher K removal. However, both hand weeding twice (W₁) and mechanical weeding twice (W₃) on 20 and 40 DAS were significantly superior to unweeded control (W₄) and were on par with each other in affecting the K removal by weeds.

There was no significant interaction effect between preparatory tillage and weed management methods on K removal by the weeds.

4.4. WEED CONTROL EFFICIENCY

Sunflower

Preparatory tillage and weed management methods influenced the weed control efficiency (WCE) (Table 45). Disc ploughing followed by cultivator tillage twice (T₄) registered higher WCE at 30, 60 DAS and at harvest, which were closely followed by mould board ploughing followed by cultivator tillage twice (T₃) at all the growth stages. Lowest WCE was recorded by cultivator tillage twice (T₂) at 30 DAS and by country plough tillage twice (T₁) both at 60 DAS and at harvest.

Among the weed management methods, obviously the highest WCE was recorded by the pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W₂) and both hand weeding twice (W₁) and

Table 45. Effect of preparatory tillage and weed management methods on weed control efficiency and weed index in sunflower-maize cropping

Treatments	Sunflower				Maize			
	Weed control efficiency (%)			Weed index (%)	Weed control efficiency (%)			Weed index (%)
	30 DAS	60 DAS	Harvest		30 DAS	60 DAS	Harvest	
T₁	38.82	42.57	45.74	16.80	42.04	45.22	47.36	15.71
T₂	32.90	45.95	50.04	15.64	32.24	45.47	49.18	14.11
T₃	46.31	51.52	58.16	5.31	50.45	61.43	60.00	3.55
T₄	50.50	60.80	59.25	10.53	54.74	62.93	60.97	10.57
T₅	40.74	48.29	49.07	18.98	46.56	52.12	52.14	17.50
W₁	51.27	63.74	68.62	10.26	52.33	64.39	68.44	7.47
W₂	70.57	80.48	78.50	-	78.87	85.19	82.07	-
W₃	45.58	61.49	62.69	11.14	49.62	64.17	65.22	8.06
W₄	-	-	-	32.40	-	-	-	33.63

Data statistically not analysed

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

mechanical weeding twice (W_3) were comparable with each other in controlling the weeds by recording lower WCE than W_2 .

Maize

Significant variation was observed by preparatory tillage and weed management methods on weed control efficiency (WCE) (Table 45). Disc ploughing followed by cultivator tillage twice (T_4) resulted in the highest WCE which was closely followed by mould board ploughing followed by cultivator tillage twice (T_3) at 30 and 60 DAS as well as at harvest. Cultivator tillage twice (T_2) recorded lower WCE at 30 DAS and country plough tillage (T_1) resulted in lower WCE both at 60 DAS and at harvest, which was closely followed by cultivator tillage twice (T_2).

In case of weed management methods, pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) resulted in the highest WCE. Both hand weeding twice (W_1) and mechanical weeding twice (W_2) were comparable with each other in controlling the weeds at all the stages.

4.5. WEED INDEX

Sunflower

Grain yield with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (W_2) was taken as basis to work out weed index (WI). Disc ploughing (T_4) and mould board ploughing (T_3) followed by cultivator tillage performed better and recorded lower WI. Minimum tillage (T_5) found to record higher WI, which performed very poorly among the tillage methods (Table 45).

Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were found better and recorded the lowest WI. Unweeded control (W_4) resulted in the highest WI and performed very poorly.

Maize

Yield with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) was taken as basis to work out the weed index (WI) (Table 45). Mould board ploughing followed by cultivator tillage twice (T_3) resulted in the lowest WI. The highest WI was recorded by minimum tillage (T_5).

Among the weed management methods, hand weeding twice (W_1) recorded the lowest WI, which was closely followed by mechanical weeding twice (W_3). Unweeded control (W_4) performed very poorly and resulted in the highest WI.

4.6. ECONOMIC ANALYSIS

The general cost of cultivation, cost of treatments, gross and net returns, benefit-cost ratio and per day returns were worked out for all the treatment combinations for both the crops.

Sunflower

The highest gross returns of Rs.21,364/ha and net returns of Rs.12,681/ha were obtained with preparatory tillage by disc ploughing followed by cultivator tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (T_4W_2) (Table 46). Cultivator tillage twice in combination with the herbicidal + manual weeding (T_2W_2) was the next best in recording higher gross (Rs.21,294/ha) and net (Rs.13,144/ha) returns. Combination of preparatory tillage with mould board ploughing followed by cultivator tillage and herbicidal + manual weeding (T_3W_2) was also in line to record higher gross (Rs.21,280/ha) and net (Rs.12,597/ha) returns next to T_2W_2 . Minimum tillage combined with unweeded control (T_5W_4) recorded the lowest gross (Rs.11,550/ha) and net returns (Rs.5,310/ha) followed by country plough tillage combined with unweeded control (T_1W_4), registering Rs.12,194/ha and Rs.5,354/ha as gross and net returns, respectively.

Table 46. Economics of preparatory tillage and weed management methods in sunflower

Treatments	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B : C ratio	Per day income (Rs./ha)
T ₁ W ₁	8190	18270	10080	2.23	112
T ₁ W ₂	8350	20888	12538	2.50	139
T ₁ W ₃	8370	18158	9788	2.16	108
T ₁ W ₄	6840	12194	5354	1.78	59
T ₂ W ₁	7990	18956	10966	2.37	121
T ₂ W ₂	8150	21294	13144	2.61	146
T ₂ W ₃	8170	18732	10562	2.29	117
T ₂ W ₄	6640	12866	6226	1.93	69
T ₃ W ₁	8523	19530	11007	2.29	122
T ₃ W ₂	8683	21280	12597	2.45	140
T ₃ W ₃	8703	19362	10659	2.22	118
T ₃ W ₄	7173	13440	6267	1.87	69
T ₄ W ₁	8523	20426	11903	2.39	132
T ₄ W ₂	8683	21364	12681	2.46	141
T ₄ W ₃	8703	20104	11401	2.31	126
T ₄ W ₄	7173	14560	7387	2.02	82
T ₅ W ₁	7590	17808	10218	2.34	113
T ₅ W ₂	7750	21000	13250	2.70	147
T ₅ W ₃	7770	17696	9926	2.27	110
T ₅ W ₄	6240	11550	5310	1.85	59

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

The highest benefit of Rs.2.70 was obtained as a return for every rupee invested on cost of cultivation with minimum tillage combined with pre-emergence application of pendimethalin 0.50 lit/ha + metolachlor 0.50 lit/ha followed by hand weeding on 40 DAS (T_5W_2). Cultivator tillage twice in combination with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (T_2W_2) was the next best treatment to fetch a return of Rs.2.61 for every rupee invested on cultivation. Lowest benefit-cost ratio (1.78) was recorded with country plough tillage combined with unweeded control (T_1W_4) followed by (1.85) minimum tillage twice with unweeded control (T_5W_4).

Higher net returns of Rs.147/day was obtained with minimum tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (T_5W_2). Cultivator tillage twice in combination with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by hand weeding on 40 DAS (T_2W_2) fetched Rs.146/ha as per day returns. Lowest per day returns of Rs.59/ha was obtained with either minimum tillage (T_5W_4) or country plough tillage (T_1W_4) combined with unweeded control

Maize

Preparatory tillage with disc ploughing followed by cultivator tillage combined with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_4W_2) recorded the highest gross returns of Rs.34,306/ha and net returns of Rs.24,938/ha (Table 47). The next best treatment combination was preparatory tillage with mould board ploughing followed by cultivator tillage and weed management with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (T_3W_2), recording higher gross (Rs.34,179/ha) and net (Rs.24,811/ha) returns. Minimum tillage combined with unweeded control (T_5W_4) resulted in the lowest gross (Rs.18045/ha) and net (Rs.9485/ha) returns.

Highest returns of Rs.3.66 was obtained for every rupee invested on cost of cultivation with disc ploughing followed by cultivator tillage twice associated with pre-

Table 47. Economics of preparatory tillage and weed management methods in maize

Treatments	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B : C ratio	Per day income (Rs./ha)
T ₁ W ₁	9910	30218	20308	3.04	193
T ₁ W ₂	9368	33606	24238	3.58	230
T ₁ W ₃	10090	30090	20000	2.98	109
T ₁ W ₄	8560	19349	10809	2.26	102
T ₂ W ₁	9910	31460	21550	3.17	205
T ₂ W ₂	9368	34114	24749	3.64	235
T ₂ W ₃	10090	31360	21270	3.10	202
T ₂ W ₄	8560	20223	11663	2.36	111
T ₃ W ₁	9910	32197	22287	3.24	212
T ₃ W ₂	9368	34179	24811	3.64	236
T ₃ W ₃	10090	32015	21925	3.17	208
T ₃ W ₄	8560	20514	11954	2.39	113
T ₄ W ₁	9910	33405	23495	3.37	223
T ₄ W ₂	9368	34306	24938	3.66	237
T ₄ W ₃	10090	33134	23044	3.28	219
T ₄ W ₄	8560	21669	13109	2.53	124
T ₅ W ₁	9910	29836	19926	3.01	189
T ₅ W ₂	9368	33672	24304	3.59	231
T ₅ W ₃	10090	29571	19481	2.93	185
T ₅ W ₄	8560	18045	9485	2.10	90

T₁ - T₅ : Preparatory tillagesW₁ - W₄ : Weed management methods

emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_4W_2). Combination of mould board ploughing followed by cultivator tillage twice combined with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_3W_2) was the next best treatment with a benefit cost ratio of 3.64. The lowest benefit-cost ratio (2.10) was recorded with minimum tillage combined with unweeded control (T_5W_4).

Higher per day returns of Rs.237/ha was obtained with disc ploughing followed by cultivator tillage combined with pre-emergence application of atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (T_4W_2), whereas minimum tillage in combination with unweeded control (T_5W_4) recorded the lowest per day returns of Rs.90/ha. Weed management with pre-emergence application of atrazine 0.25 /ha + hand weeding on 40 DAS when combined with either cultivator tillage twice (T_2W_2) or mould board ploughing followed by cultivator tillage twice (T_3W_2) recorded higher per day returns of Rs.235 and Rs.236 respectively, than with T_4W_2 .

4.7. CROPPING SYSTEM ANALYSIS

4.7.1. Weed dry matter

Both the preparatory tillage and weed management methods significantly influenced the weed dry matter (DM) (Table 48). Weed DM in both sunflower and maize crops at all the three stages was taken together for system analysis. Disc ploughing followed by cultivator tillage twice (T_4) to preceding sunflower resulted in lower weed dry matter at 30, 60 DAS and at harvest. However, weed dry matter with mould board ploughing followed by cultivator tillage twice to sunflower alone (T_3) was comparable with that of T_4 at all the three growth stages of both the crops. Minimum tillage (T_5) registered higher weed dry matter at all the stages, which was on par with country plough tillage twice (T_1) at all the three stages. Cultivator tillage twice (T_2) was on par with the highest weed dry matter production with T_5 at 30 DAS, while T_2 was comparable with T_3 at harvest and T_2 was significantly different from all other tillage methods at 60 DAS.

Table 48. System weed dry matter as influenced by preparatory tillage and weed management in sunflower-maize cropping

Treatments	Weed dry matter (kg/ha)		
	30 DAS	60DAS	Harvest
T ₁	16.88 (331.96)	29.79 (1049)	28.12 (930.8)
T ₂	14.99 (265.60)	24.44 (737.3)	22.51 (624.3)
T ₃	11.74 (164.92)	19.33 (493.8)	18.14 (420.3)
T ₄	11.19 (152.87)	16.49 (365.9)	16.02 (331.6)
T ₅	16.24 (314.23)	32.79 (1309)	31.09 (1176.3)
SEd	0.79	2.09	1.96
CD (5%)	1.84	4.84	4.53
W ₁	13.96 (222.78)	23.12 (641.66)	20.41 (497.4)
W ₂	2.37 (78.85)	13.31 (209.67)	14.30 (236.1)
W ₃	14.53 (238.70)	23.56 (663.06)	21.95 (578.3)
W ₄	19.97 (443.33)	23.26 (1650.15)	36.07 (1474.1)
SEd	0.66	1.43	1.28
CD (5%)	1.34	2.93	2.63
<u>T at W</u> SEd	1.50	3.48	3.17
CD (5%)	NS	NS	NS
<u>W at T</u> SEd	1.47	3.21	2.88
CD (5%)	NS	NS	NS

Figures in parenthesis are original values

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha with hand weeding on 40 DAS for sunflower and atrazine 0.25 kg/ha for maize followed by hand weeding on 40 DAS (W_2) resulted in the lowest weed dry matter. Whereas, unweeded control (W_4) recorded the highest weed dry matter at all the growth stages. Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were significantly superior to W_4 in recording lower weed dry matter and both W_1 and W_3 were on par with each other at 30 and 60 DAS as well as at harvest.

There was no significant interaction effect between preparatory tillage and weed management methods in influencing the weed dry matter at all the growth stages.

4.7.2. Plant dry matter production

Plant dry matter production (DMP) was significantly altered by both preparatory tillage and weed management methods (Table 49). Dry matter production of both sunflower and maize crops was taken together for system plant DMP as a whole. Preparatory tillage with mould board ploughing followed by cultivator tillage twice to preceding sunflower (T_3) recorded higher plant DMP at all the three stages. However, T_3 was comparable with disc ploughing followed by cultivator tillage twice (T_4) and cultivator tillage twice (T_2) at 30 DAS alone. But, the plant DMP with T_3 and T_4 was comparable at 60 DAS and at harvest. Lowest plant DMP was recorded by minimum tillage (T_5), which was on par with both T_2 and country plough tillage twice (T_1) at 30 and 60 DAS as well as at harvest.

In case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha with a hand weeding on 40 DAS for sunflower and atrazine 0.25 kg/ha followed by hand weeding on 40 DAS (W_2) for maize resulted in higher plant DMP which was comparable with both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS at later growth stages. But W_1 and W_3 were on par with each other and significantly better than W_4 at 30 DAS.

Plant DMP was not significantly affected by the interaction effect between preparatory tillage and weed management methods at any stage.

4.7.3. System productivity

Yield of sunflower was converted into maize grain equivalent yield and the yields of both the crops were added to obtain the system productivity. Preparatory tillage and weed management methods significantly influenced the productivity of the system (Table 49). Preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) resulted in the higher productivity (7104 kg/ha) of maize grain equivalents. Higher maize grain equivalent yield obtained with T_4 was comparable with that of mould board ploughing followed by hand weeding on 40 DAS (T_3) by recording 6870 kg/ha. Whereas, minimum tillage (T_5) registered the lowest productivity (6398 kg/ha) of the system, which was on par with country plough tillage twice (T_1). Both country plough tillage twice (T_1) and cultivator tillage twice (T_2) were on par with each other in recording higher productivity than with T_5 . Comparable productivity was obtained both with T_2 and T_3 , which were significantly better than in minimum tillage.

Higher system productivity of 7867 kg/ha of maize grain equivalent yield was obtained with pre-emergence herbicide application of pendimethalin 0.50 kg/ha + metolachlor 0.5 kg/ha with a hand weeding on 40 DAS for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2). Whereas, unweeded control (W_4) resulted in lower system productivity (4684 kg/ha). Both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were on par with each other and significantly better than W_4 in registering higher system productivity.

Productivity of the system as a whole was not significantly affected by interaction effect between preparatory tillage and weed management methods.

4.7.4. Weed index

Maize grain equivalent yield of the system with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by hand weeding at 40 DAS (W_2) was taken as a basis to work out the weed index (WI) for the system (Table 49). Disc ploughing followed by cultivator tillage twice (T_3) performed better and recorded lower WI, followed by mould board ploughing followed by

Table 49. System plant dry matter, maize grain equivalent yield and weed index as influenced by preparatory tillage and weed management methods in sunflower-maize cropping

Treatments	System plant DMP (kg/ha)			Maize grain equivalent Yield (kg/ha)	Weed index (%)
	30 DAS	60DAS	Harvest		
T ₁	1289	10155	12892	6526	16.06
T ₂	1355	10583	13272	6749	14.60
T ₃	1450	11803	14777	6870	4.12
T ₄	1444	12188	14880	7104	10.55
T ₅	1250	9741	12446	6397	17.97
SEd	45.80	539	567	142	-
CD (5%)	105.62	1243	1307	328	-
W ₁	1397	11870	14931	7210	8.37
W ₂	1495	13354	16233	7867	-
W ₃	1392	12105	14767	7156	9.05
W ₄	1147	6248	8683	4684	33.24
SEd	34.27	726	774	320	-
CD (5%)	69.99	1484	1582	655	-
<u>T at W</u> SEd	80.63	1507	1604	637	-
CD (5%)	NS	NS	NS	NS	-
<u>W at T</u> SEd	76.63	1625	1732	717	-
CD (5%)	NS	NS	NS	NS	-

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

cultivator tillage twice (T_4). Weed index with cultivator tillage twice (T_2) was next to WI with T_3 . Higher WI was recorded with minimum tillage (T_5).

Among the weed management methods, both hand weeding twice (W_1) and mechanical weeding twice (W_3) on 20 and 40 DAS were comparable and recorded lower WI and unweeded control (W_4) resulted in higher weed index.

4.7.5. System economics

The highest gross returns of Rs.47,658/ha was obtained with preparatory tillage by disc ploughing followed by cultivator tillage twice combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for the first crop of sunflower and atrazine 0.25 kg/ha followed by hand weeding on 40 DAS for maize (T_4W_2) (Table 50). Preparatory tillage by either with cultivator tillage twice (T_2W_2) or mould board ploughing followed by cultivator tillage twice (T_3W_2) for sunflower alone in combination with herbicidal + manual weeding for both sunflower and maize crops was the next best to T_4W_2 , in recording higher gross returns of Rs.47,478 and Rs.47,430/ha, respectively. Minimum tillage combined with unweeded control (T_5W_4) resulted in the lowest gross returns of Rs.25,284/ha. Highest net returns of Rs.29,922/ha was obtained with cultivator tillage twice combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for followed by hand weeding on 40 DAS (T_2W_2) for maize. Preparatory cultivation either with minimum tillage (T_5W_2) or disc ploughing followed by cultivator tillage twice (T_4W_2) for sunflower alone in combination with herbicidal + manual weeding on 40 DAS for both sunflower and maize fetched a net returns of Rs.29,682 and Rs.29,607/ha, respectively, which were comparable with T_2W_2 . Minimum tillage combined with unweeded control (T_5W_4) resulted in the lowest net returns of Rs.10,484/ha with both the crops in the system.

Higher benefit-cost ratio (2.73) was recorded with T_5W_2 and the lowest benefit- cost ratio (1.70) was recorded with minimum tillage combined with unweeded control (T_5W_4) followed by (1.75) country plough tillage combined with unweeded control (T_1W_4). Higher per day returns of Rs.155/ha was obtained with cultivator tillage combined with pre-emergence

Table 50. Economics of preparatory tillage and weed management methods in system

Treatments	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B : C ratio	Per day income (Rs./ha)
T ₁ W ₁	18100	41604	23504	2.29	120
T ₁ W ₂	17718	46656	23938	2.63	148
T ₁ W ₃	18460	41400	22940	2.24	117
T ₁ W ₄	15400	26976	11570	1.75	59
T ₂ W ₁	17900	43266	25366	2.41	130
T ₂ W ₂	17518	47430	29922	2.70	155
T ₂ W ₃	18260	43020	24760	2.35	127
T ₂ W ₄	15200	28278	13078	1.86	67
T ₃ W ₁	18433	44370	25937	2.40	133
T ₃ W ₂	18051	47478	29427	2.63	151
T ₃ W ₃	18793	44082	25289	2.34	129
T ₃ W ₄	15733	28956	13223	1.84	67
T ₄ W ₁	18433	46146	27713	2.50	142
T ₄ W ₂	18051	47658	29607	2.64	151
T ₄ W ₃	18793	45666	26873	2.42	137
T ₄ W ₄	15733	31026	15293	1.97	78
T ₅ W ₁	17500	40920	23420	2.33	120
T ₅ W ₂	17118	46800	29682	2.73	152
T ₅ W ₃	17860	40536	22676	2.26	116
T ₅ W ₄	14800	25284	10484	1.70	53

T₁ - T₅ : Preparatory tillages

W₁ - W₄ : Weed management methods

application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha followed by hand weeding on 40 DAS for maize (T₂W₂). Minimum tillage combined with unweeded control (T₅W₄) recorded the lowest (Rs.53/ha) per day returns in sunflower-maize cropping system.

DISCUSSION

CHAPTER V

DISCUSSION

Tillage is the management practice which has major impact primarily on weed population dynamics. Preparatory tillage helps in controlling weeds by burying weed seeds and emerged weed seedlings, leaving a rough surface hindering weed seed germination and exposing underground parts of perennial weeds leading to desiccation. Further, tillage controls weeds by loosening the surface of the soil which facilitates effective cultivation and provides a clean uniform surface for efficient incorporation and action of herbicides.

During early part of crop growth stages, weeds are considered as one of the major threats of crop production. Uncontrolled weeds during early critical crop growth phases, cause considerable reduction in growth and yield of crops. Any attempt made to manage the weed menace during critical crop-weed competition period, consequently to improve the crop productivity could be the most appreciated approach of crop cultivation. Preparatory tillage combined with weed management methods form the primary component of agronomic practices advocated for higher productivity of crops. Hence, field investigation was made to identify the influence of preparatory tillage and weed management methods on weed population dynamics and the productivity of sunflower-maize cropping system under irrigated condition. The results of the field experiments presented in chapter IV are discussed here under.

5.1. Influence of preparatory tillage and weed management methods on weed dynamics in sunflower-maize cropping

5.1.1. Weed flora

Weed flora of the experimental field during the cropping period primarily composed of grasses, sedges and broad-leaved weeds. The dominant weed species noticed were *Cynodon dactylon* (16.29%), *Dactyloctenium aegyptium* (7.4%), *Cyperus rotundus* (13.13%), *Trianthema portulacastrum* (15.92%), *Parthenium hysterophorus* (15.92%) and *Digera arvensis* during sunflower cropping period. The predominance of

Effective control of weeds with hand weeding



Effective weed control with herbicide



Plate 5. Weed control as influenced by hand weeding and pre-emergence herbicide

these weed species in sunflower cropped fields under Coimbatore condition was earlier reported by Ramachandra Prasad (1993). Similarly, in maize also *Digera arvensis* (9.94%), *Trianthema portulacastrum* (13.60%), *Dactyloctenium aegyptium* (9.94%), *Cynodon dactylon* (18.12%) and *Cyperus rotundus* (15.29%) were found to be dominated weeds. The predominant occurrence of these weed species in sunflower-maize cropping system could probably be attributed to the ecological adaptation and dominance of the above listed weeds in black clay loam deep soils of Coimbatore region. Such dominant occurrence of *Trianthema portulacastrum*, *Digera arvensis*, *Parthenium hysterophorus*, *Dactyloctenium aegyptium*, *Cynodon dactylon* and *Cyperus rotundus* was reported by Ramesh (1998) in maize fields of clay loam soils under Coimbatore conditions.

5.1.2. Weed density

The lowest density of total weeds was observed in preparatory tillage with either disc ploughing (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice, which might probably be due to the inversion of surface soil by disc ploughing and burial of weed seed by mould board ploughing followed by thorough mixing of disturbed soil surface by cultivator tillage (Plate 7). Minimum tillage (T_5) was found to record the highest total weed density mainly constituted by the highest densities of both grasses and broad-leaved weeds. This might be due to the deposition of seeds of predominant annual weeds near the soil surface as the soil was not much disturbed in minimum tillage (T_5). The results are in conformity with the observation of Clements *et al.* (1996), who observed that greater deposition of weed seeds at the soil surface with minimum tillage. However, the lower total weeds at early crop growth stage with either country plough tillage (T_1) or cultivator tillage (T_2) against minimum tillage (T_5) could be attributed to the early germination of seed propagated weeds and control by early exposure of weed seedlings for any one of the weed management methods.

Total weed density was reduced in sunflower cropping by the pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha (Plate 5) and in maize cropping by pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (W_2) for both the crops. This might probably be due to the control

Increased broad-leaved weed population



Reduced broad-leaved weed population



Plate 7. Weed population as influenced by preparatory tillage with country plough

of weeds at the germination phase of early stages of weed growth by the pre-emergence herbicides and significant reduction at later growth stages as late germinating weeds were removed by hand weeding. The results are in corroboration with the findings of Arti Khare and Jain (1995) who found that the combination of pre-emergence application of anilophos 0.4 kg/ha followed by a hand weeding on 40 DAS gave the lowest weed infestation in upland rice. Efficient control of both seed-germinated weeds by pendimethalin and sedge weed by metolachlor with combined application of pendimethalin and metolachlor in sunflower could be the probable reason for reduction in total weed population in sunflower at the early growth stage. This finding is in accordance with the results of Chennappagounder *et al.* (2000) who stated that metolachlor 0.5 kg/ha + pendimethalin 0.75 kg/ha proved to be the best combination in reducing the weed density at critical stages of crop growth. Either hand weeding twice (W_1) or mechanical weeding with rotary weeder (W_3) twice on 20 and 40 DAS significantly reduced the total weed density (Plate 6) as compared to unweeded control (W_4) as hand weeding or mechanical weeding could reduce the weed stand at early stages of crop growth.

Relative density of grasses (24.82%) and sedge (13.16%) were proportionately less than broad-leaved weeds (62.00%) either with country plough tillage (T_1) or cultivator tillage twice (T_2) consequently resulting in the lowest density of grassy and sedge weed population (Fig 7 & 8.). These findings are in accordance with the observation of Sathyamoorthi *et al.* (2001) who reported that cultivator tillage twice recorded the lowest grassy and sedge weed population in irrigated upland ecosystem. But, at the end of the cropping system, minimum tillage (T_5) resulted in higher sedge weed density, as the rooting depth of the soil during the crop interval was not disturbed which might have caused the slow emergence and establishment of sedge weed from the deeper soil layers. Similar observations were made earlier by Buhler *et al.* (1994), who have recorded higher population of perennial weeds in reduced tillage systems as the rooting depth of the soil was not disturbed. Minimum tillage (T_5) recorded the highest grass weed density as it could not cause much disturbance to the vegetative propagules of the grassy weeds in which the relative density of grasses mainly contributed by



Unchecked weed growth



Plate 6. Weed population as influenced by

Cynodon dactylon was also higher (28.79%). The highest sedge density recorded with disc ploughing followed by cultivator tillage twice (T₄) could be attributed to the inversion of the soil, which in turn might have brought up the rhizomes of the only sedge weed, *Cyperus rotundus* from the deeper soil layers. Either, disc ploughing (T₄) or mould board ploughing (T₃) followed by cultivator tillage twice recorded the lowest broad-leaved weed population, which might be due to the lower relative density of broad-leaved weeds (42.80% to 55.75%) with these tillage methods as a result of deep burial of weed seeds in the deeper soil layers. This result is in line with the findings of Sathyamoorthi *et al.* (2001) who observed that preparatory tillage with tractor drawn disc or mould board ploughing followed by cultivator tillage twice reduced the broad-leaved weed population in maize under irrigated conditions. Minimum tillage (T₅) registered the highest broad-leaved weed population as the weed seeds from the previous season cropping deposited in the surface layers could emerge and establish and seeds disseminated by wind viz., *Parthenium hysterophorus* and *Digera arvensis* might have been retained due to the rough surface of the soil in the minimum tillage (T₅) also would have contributed to the density of the broad-leaved weeds. This correlates with the findings of Mester and Buhler (1986) and Blackshaw *et al.* (1994) who reported that no tillage could maximize the potential of weed growth due to the weed seed accumulation at or near the firm soil surface with minimum disturbance.

Considerable reduction in grass, sedge and broad-leaved weed density was observed with integrated weed management by pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize cropping followed by a hand weeding on 40 DAS (W₂) for both the crops. Application of herbicides at pre-germinated as well as at early establishment of weeds in both the crops found to control graminaceous weeds which dominated the experimental field upto 30 DAS, sedge and broad-leaved weeds during early growth stages of both the crops. Inhibitory effect on protein synthesis by metolachlor (Deal *et al.*, 1980) and degradation of the chloroplasts and swelling followed by disruption of granal discs of the emerging weed seedlings by atrazine (Hill *et al.*, 1968) eventually causing the death of tissue and whole plant could be attributed to the reduction of weed population with

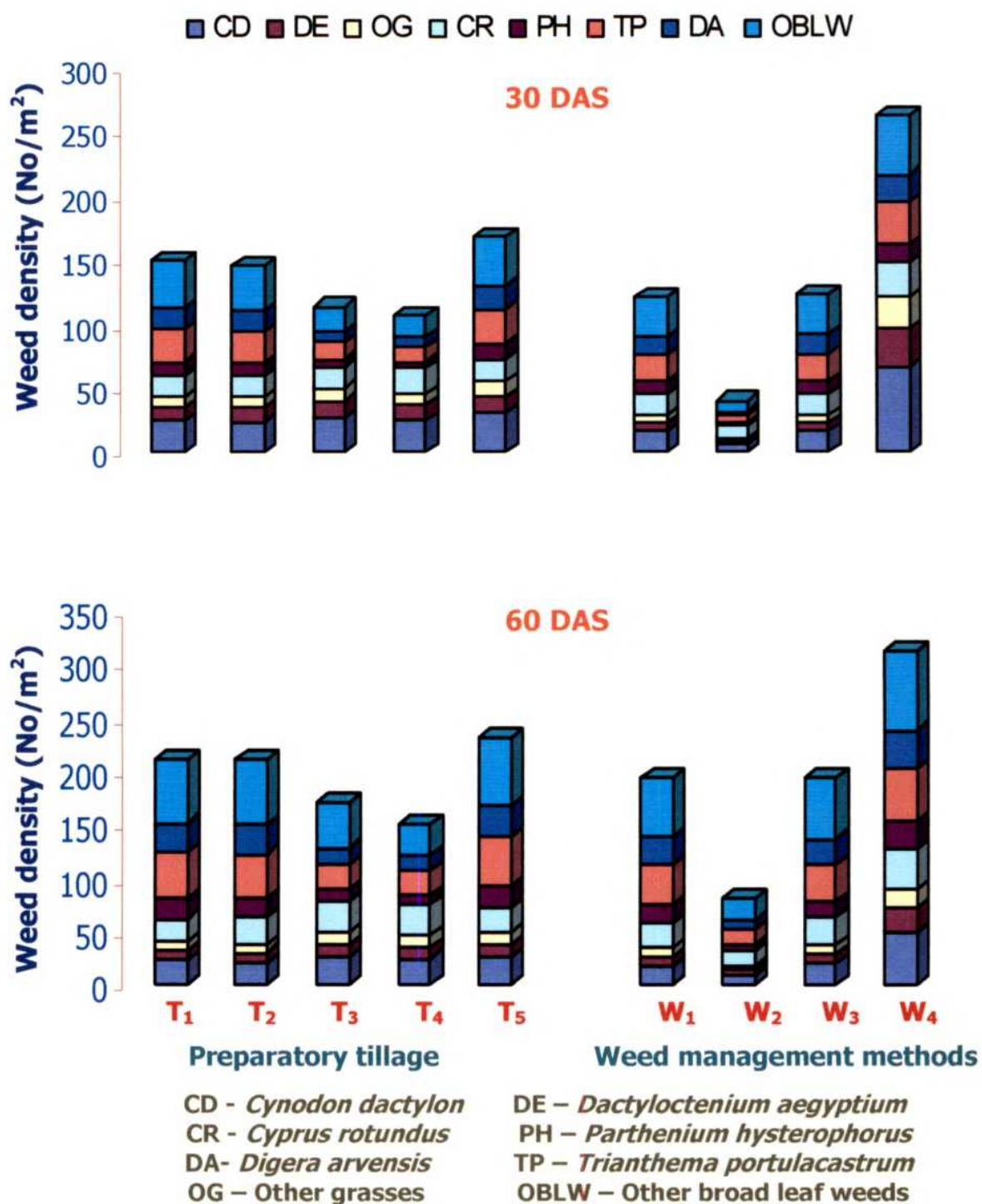


Fig 3. Density of individual weeds as influenced by preparatory tillage and weed management methods in sunflower

integrated management in both crops. Rout and Satapthy (1996) had also made similar observations with a reduction of weed density in maize due to the application of atrazine or metolachlor. Obviously unweeded control (W₄) resulted in higher grasses, sedge and broad-leaved weed population due to unchecked and increased weed growth at all the growth stages of crops. Interaction effect between preparatory tillage and weed management methods was found on the grass weed population at later growth stages in maize crop and on sedge and broad-leaved weed population in both the crops.

Lower density of grassy weeds at later growth stages of maize with pre-emergence application of atrazine 0.25 kg/ha + hand weeding on 40 DAS in association with preparatory tillage by mould board ploughing followed by cultivator tillage (T₃W₂) to the preceding sunflower crop could be attributed to the better exposure of grassy weeds and their seeds to herbicide and manual removal in well distributed soil layers due to deep tillage. Similarly, reduction of broad-leaved and sedge weeds with cultivator tillage coupled with integrated weed management by herbicide + hand weeding might be due to increased efficiency of weed management methods against broad-leaved weeds in disturbed surface soil layers by cultivator tillage.

Increased efficiency of different preparatory tillage practices on weed control could be further increased by integration of weed management with pre-emergence application of atrazine at 0.25 kg/ha followed by one hand weeding on 35 DAS in maize as earlier reported by Chinnusamy *et al.* (2002). Minimum tillage + herbicide followed by hand weeding on 40 DAS (T₅W₂) resulted in the highest grass, sedge and broad-leaved weed population in which the herbicide might not have penetrated into the deeper soil layers due to the interception of the plant residue on the soil surface. This was also earlier reported by Ghadiri *et al.* (1989) who have stated that reducing or eliminating tillage might influence the behavior of soil surface applied herbicides by reducing the amount reaching the soil and altering the distribution by intercepting the herbicide applied through the plant residue on the soil surface.

Higher densities of *Cynodon dactylon* and *Dactyloctenium aegyptium* were recorded with the minimum tillage (T₅) as these weeds are vegetatively propagated and minimum tillage had not caused much disturbance to the weeds present. The lowest densities of *Cynodon dactylon*, *Dactyloctenium aegyptium* and *Cyperus rotundus* were observed with country plough (T₁) or cultivator tillage (T₂), because the shallow tillage might have facilitated better exposure of vegetative propagules to the hot sun and would have been desiccated leading to loss of viability of such propagating materials. Disc ploughing followed by cultivator tillage (T₄) resulted in the highest *Cyperus rotundus* density as disc ploughing might have resulted in the inversion of soil layers and the rhizomes of *Cyperus rotundus* might have been brought up to the surface layers of the soil favouring germination and establishment of sedge weed.

Lesser number of *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* observed with disc ploughing followed by cultivator tillage twice (T₄) at all the growth stages of crops might probably be due to the deep burial of weed seeds devoiding germination or reaching a state of dormancy during the current season. This is in line with the finding of Chinnusamy *et al.* (2002) who reported that tractor drawn disc ploughing or mould board ploughing followed by cultivator tillage twice reduced the broad-leaved weed population in black clay loam soils. Changes in the preparatory tillage practices influenced the weed species dominance as the vertical distribution of the weed seeds might have been influenced as per the variation in ploughing pattern of different tillage methods. The observation is in coherence with the findings of Grime *et al.* (1981) who reported that weed communities differed because of the marked sensitivity of those communities to different types of disturbance caused by various tillage systems.

Pre-emergence application of herbicides followed by a hand weeding on 40 DAS reduced the density of *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Cyperus rotundus*, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* in both the crops (Fig 3 & 4.). Hand weeding twice (W₁) and mechanical weeding twice (W₃) also found to be significantly superior over the unweeded control (W₄) in reducing the density of the dominant weed species in the sunflower-maize cropping system. Weed

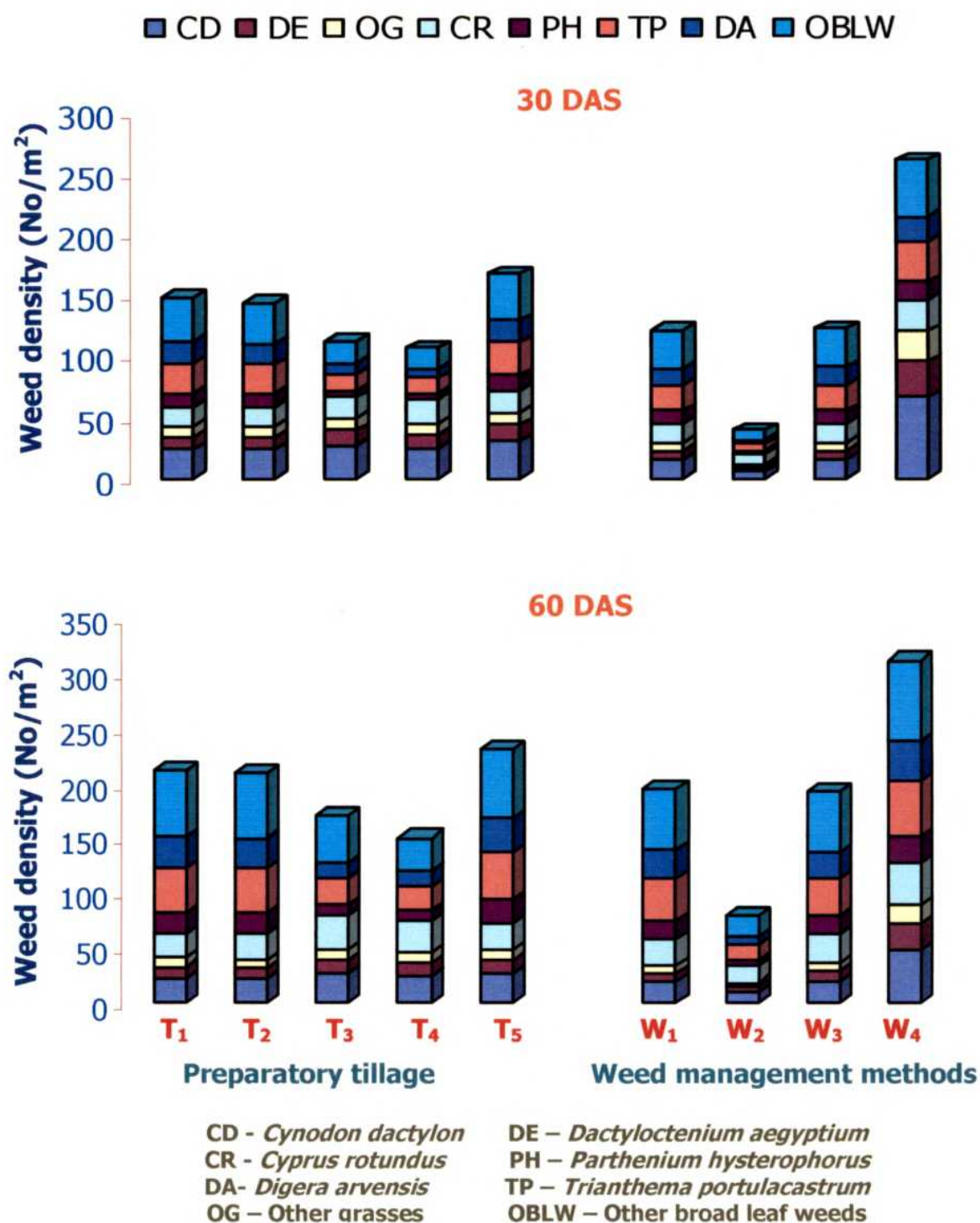


Fig 4. Density of individual weeds as influenced by preparatory tillage and weed management methods in maize

management either with manual or mechanical method reduced the weed stand in the earlier crop growth stages which might have lowered the weed seed return and ultimately the densities of weed species would have been reduced. Similar findings were made earlier by Pleasant *et al.* (1990), who have recorded reduced weed stand and lower weed seed returns to the soil in rice-maize-soybean cropping system.

Interaction effect between tillage and weed management methods was found to be significant in altering the densities of *Cyperus rotundus*, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis*. Pre-emergence application of herbicides combined with cultivator tillage twice (T_2W_2) reduced the density of *Cyperus rotundus*. Combination of pre-emergence herbicide application followed by a hand weeding with disc ploughing followed by cultivator tillage (T_4W_2) reduced the density of the broad-leaved weeds such as *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* due to the increased efficiency of disc plough tillage coupled with the application of herbicides in association with a late hand weeding in controlling the weeds which are predominantly seed germinated weeds from the shallow surface soil layers. Higher density of vegetatively propagated sedge, *Cyperus rotundus* and seed germinated broad-leaved weeds like *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* in minimum tillage combined with pre-emergence herbicide application might probably be due to the plant residues on the soil surface which might have intercepted the penetration of herbicides into the soil and the efficiency of the herbicides might have hindered resulting in higher densities of predominant weeds.

5.1.3. Weed dry matter

Weed dry matter is the most important parameter to assess the weed competitiveness for the crop growth and productivity. Sparse weeds with high biomass might be more competitive for crops than dense weeds with lesser dry matter.

Preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) reduced the weed dry matter significantly because of the reduced total weed density with lesser individual weed biomass. Country plough tillage (T_1) resulted in the highest weed

**Reduced broad-leaved weed population
with disc tillage**

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**Profused weed population with minimum
tillage**



**Plate 8. Weed population as influenced by
preparatory tillage with disc ploughing
and minimum tillage after sunflower**

dry matter at 30 DAS and as the crop growth stages advanced, minimum tillage (T_5) recorded the highest weed dry matter (Fig 5) due to the increased total weed density and higher proportion of broad-leaved weeds (67.38%) which might have contributed much share to the total weed dry matter (Plate 8). These results are in accordance with the findings of Legere and Sampson (1999) and Barberi and Cascio (2001) who have observed higher weed dry matter with more than 60 % of weed seedlings emerged from the surface soil layers in non-inversion chisel ploughing and no tillage systems. Considerable reduction in weed dry weight recorded with pre-emergence herbicide application followed by a hand weeding (W_2) at later growth stages might be attributed to the minimum number of total weeds with lesser biomass in both the cropping period (Plate 9). Nearly 40% reduction in weed dry matter was noticed with integrated herbicidal + manual weeding methods than with unweeded control (W_4), because of reduced total density of weeds in the herbicide applied plots at early growth stages and manual weeding at later growth stages of both the crops. Similar reduction in weed dry matter was earlier recorded by Balasubramanian *et al.* (2001) in sunflower with herbicidal + manual weeding during summer and kharif seasons. Further, these results are in conformity with those of Srinivas and Sathyanarayan (1994) and Sharma *et al.* (1998) who have recorded lower weed dry matter with herbicidal weed management in maize due to lesser total weed density and higher weed control efficiency.

Manual weeding (W_1) or mechanical weeding twice (W_3) on 20 and 40 DAS of both crops reduced the weed dry matter, but were found to be the next best to early herbicidal + late manual weeding (W_2). Weed removal after its germination and establishment upto either 20 or 40 DAS both in sunflower and maize crops, might have failed to reduce the weed dry matter from the inception of their germination, which was further proved with higher total weed population in manual or mechanical weeding.

Effective weed control with atrazine



Unchecked weed growth with unweeded control



Plate 9. Weed growth as influenced by country plough tillage with atrazine and unweeded control in succeeding maize

5.2. Influence of preparatory tillage and weed management methods on productivity of individual crops in sunflower-maize cropping

5.2.1. Crop yield

The productivity of crops mainly depends on the efficient and effective resource management, particularly weeds. Weeds being a serious negative factor in crop production are mainly responsible for marked losses of crop yields. Weeds that germinate and grow along with crop plants deplete considerable amount of costly fertilizer nutrients as well as available moisture in addition to the high competitiveness for space and light. Further, it has been well recognised that for sustaining the crop productivity and maintaining the soil-crop ecosystems, the associated undesirable vegetation, namely weeds have to be managed below the economic threshold levels. Herbicidal weed management is one of the main factors enabling intensification of crop cultivation in the agriculture in the past decades. However, environmental concerns along with economic issues ended with the thinking that almost total dependence on herbicidal weed management needs to be changed. This would led to the development of strategies for integrated and sustainable weed management methods including preparatory tillage associated with manual and mechanical weeding. The development of such integrated weed management methods requires a thorough qualitative insight in to the weed population dynamics in the crop ecosystems and their effects on the productivity of individual crops and cropping systems. Hence, the influences of different preparatory tillage and weed management methods on the productivity of sunflower-maize crops are discussed with related parameters.

Sunflower

The productivity of sunflower measured in terms of seed yield was influenced by both preparatory tillage and weed management methods in sunflower-maize cropping system. Higher seed yield (1365 kg/ha) (Fig 9.) of sunflower obtained with disc ploughing followed by cultivator tillage twice (T₄) could be attributed to better growth parameters such as plant DMP, crop growth rate, relative growth rate and net assimilation rate reflecting with favourable yield attributes viz., capitulum diameter, weight of the

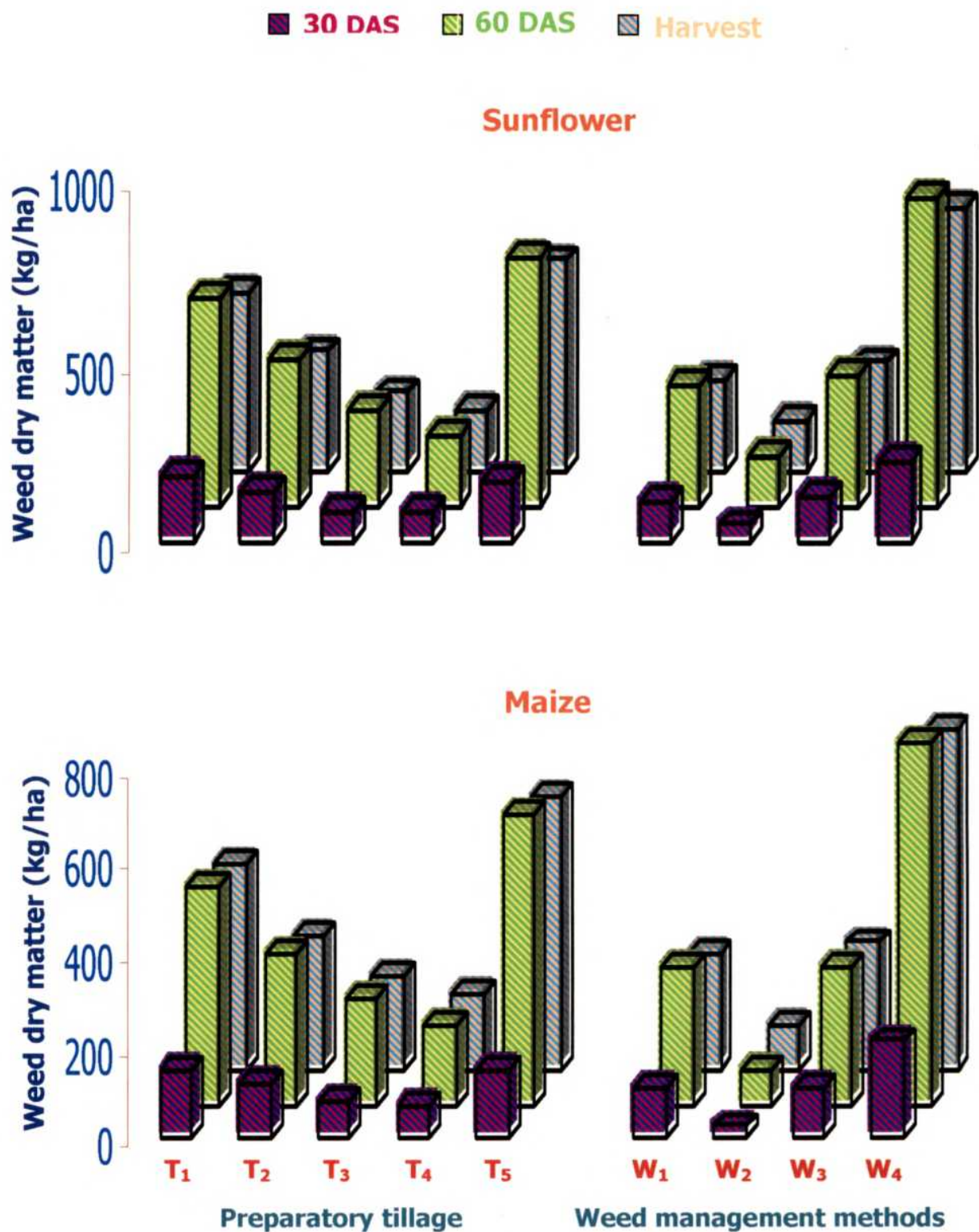


Fig 5. Dry matter of weeds as influenced by preparatory tillage and weed management methods in sunflower- maize cropping system

individual capitulum and higher test weight of seeds in sunflower. Higher, weed control efficiency with a considerable reduction in weed dry matter (Fig.6) as a result of reduced total and dominant weed densities contributed for favourable growth and yield attributes of sunflower with deep ploughing by discs followed by cultivator tillage (T_4). This is in line with findings of Rai and Yadav (1979) who have confirmed the increased grain yield in sunflower with deep cultivation without stubble mulching, due to improved root development and soil water use to greater depths. Comparable yield of sunflower with deep ploughing by mould board (T_3) and disc plough (T_4) and both with cultivator tillage twice (T_2) which might probably be due to better weed control reflected through lesser weed dry weight and density of total dominant weed species. Higher yields with these treatments might be due to deep ploughing followed by pulverisation of plough sole depth of soil layers by cultivated tillage favouring the germination of current season weed seeds and efficient control by integrating weed management methods. The lowest seed yield (1215 kg/ha) obtained with minimum tillage (T_5) among different preparatory tillage methods could be attributed to higher weed competition reflected through weed index (19.58%) and reduced growth parameters such as plant DMP, crop growth rate, net assimilation rate and affecting yield attributes recording narrow capitulums with lesser weight and lower test weight of seeds.

Higher seed yield (1511 kg/ha) of sunflower obtained with pre-emergence application of pendimethlin 0.50 + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (W_2) would be related to better growth and yield parameters as a result of efficient weed control by herbicides and manual removal of late germinating weeds. Early application of broad spectrum selective herbicide pendimethalin might have controlled seed germinated broad-leaved and grassy weeds and metolachlor controlling sedges as well as some of the vegetatively propagating grass weeds and the efficiency of herbicides was pronounced with reduced weed density and dry matter (Fig.7&8). These results are in accordance with the findings of Jat and Giri (2000) who have reported the advantages of pendimethalin in controlling weeds and increasing the yield of sunflower. Either hand weeding (W_1) or mechanical weeding twice with rotary weeder (W_3) on 20

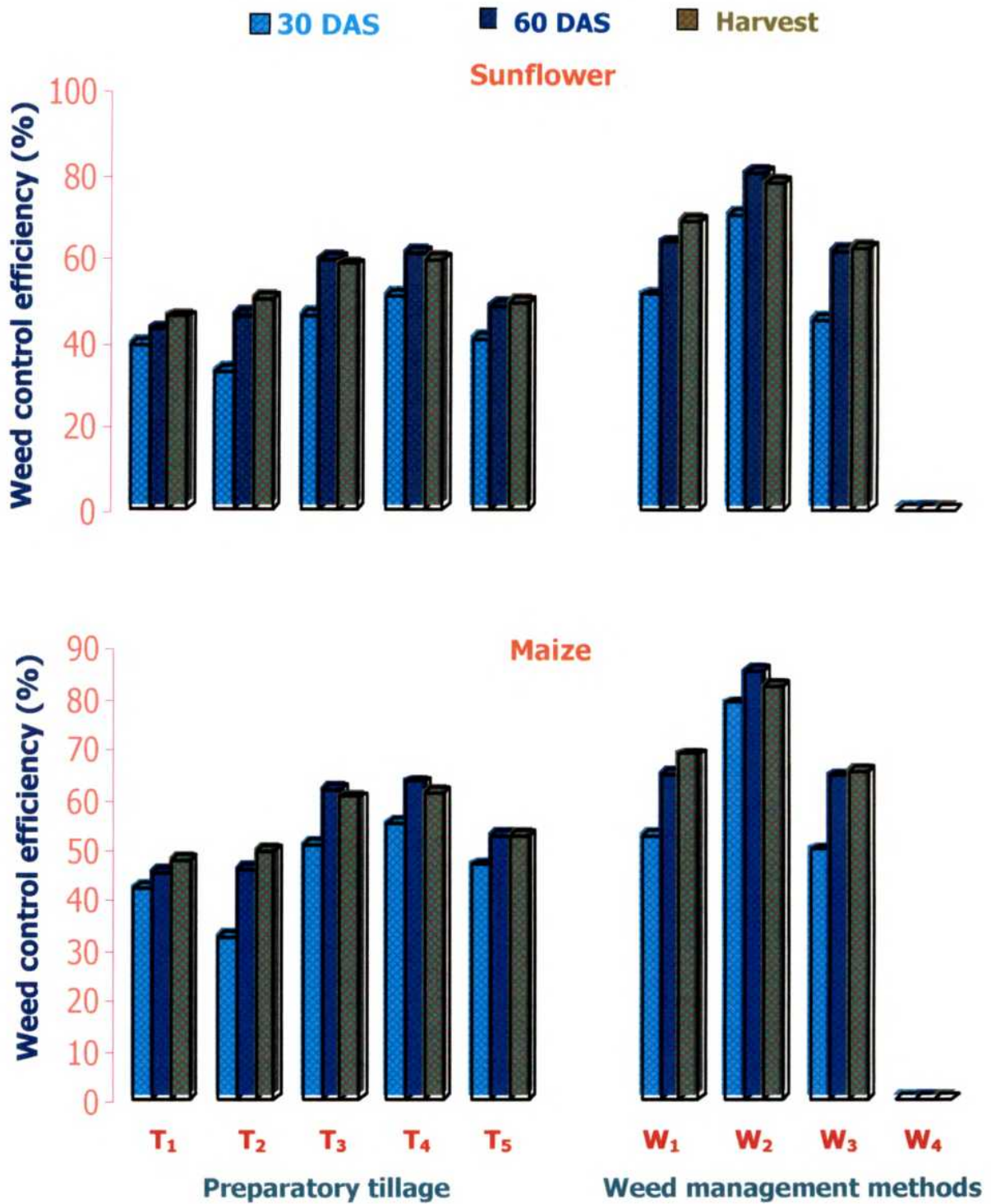


Fig 6. Effect of preparatory tillage and weed management methods on weed control efficiency in sunflower-maize cropping system

and 40 DAS, produced higher and comparable seed yields with that of herbicidal + manual weeding (W_2) indicating the efficiency of both manual and mechanical weedings in controlling the weeds during the early critical crop-weed competition stage of sunflower. These results are in line with the findings of Basavarajappa (1992) who reported the advantages of herbicidal, manual and mechanical weed control methods in increasing the seed yields markedly over unweeded control in sunflower. Unchecked weed growth recording more total and dominant weed densities with higher weed dry matter in unweeded control (W_4), obviously might have reduced the seed yield of sunflower drastically due to severe competition of weeds during critical crop growth stages. The yield reduction of 38.9% with unweeded control corroborates with the findings of Legha *et al.* (1992) who have reported 64% yield reduction with sunflower due to uninhibited growth of weeds.

Maize

Maize being a deep and dense rooted crop with faster growth rate at its early stages, expresses wide variation in its productivity due to changing crop cultivation environment. Land preparation with different tillage methods and early weed control by various weed management methods contributed maximum share on the maize yields. Deep preparatory tillage with disc plough followed by pulverisation of sub surface soil with two passes of cultivator tillage (T_4) during preceding sunflower crop season resulted in higher grain (4829 kg/ha) (Fig 9.) as well as stover (9032 kg/ha) yields of succeeding maize, which is an indication of higher efficiency of deep tillage over a long cropping period. This was further strengthened with another deep tillage treatment by mould board ploughing combined with cultivator tillage twice (T_3) during preceding sunflower crop season on the succeeding maize by recording comparable grain (4679 kg/ha) and stover yields with that of disc ploughing with cultivator tillage. Higher grain and stover yields of maize with the deep tillage treatments are highly supported with the improved growth attributes such as higher plant DMP, crop growth rate, relative growth rate, net assimilation rate and better yield attributes like length, girth and weight of individual cobs and more grains per cob as well as higher test weight. The advantages of deep tillages on maize grain and stover yields were earlier brought out by Moolani and Hukkeri (1965) as compared to medium depth of ploughing with maize. Minimum tillage (T_5) to

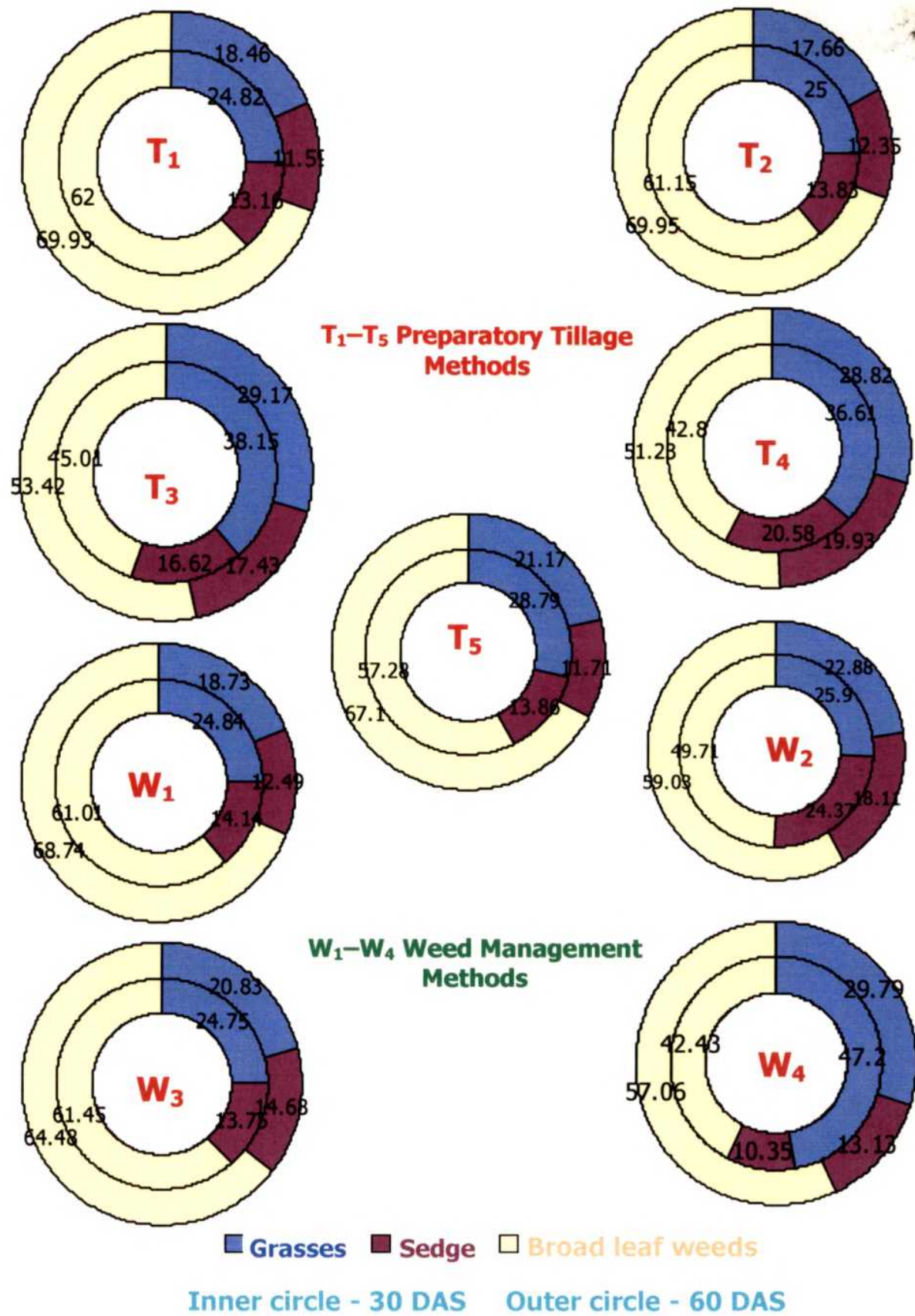


Fig 7. Relative density group wise as influenced by preparatory tillage and weed management methods in sunflower

preceding sunflower resulted in the lowest grain (4372 kg/ha) and stover (7794 kg/ha) yields of succeeding maize due to lesser growth and yield attributes. Lower grain (18.24% yield reduction) and stover yields of maize coupled with poor growth parameters like shorter plants with lesser dry matter and leaf area as well as yield attributes such as smaller cobs with lesser grains and test weights in shallow tillages like country plough tillage twice (T_1) as well as minimum tillage (T_3) during the preceding sunflower crop season might be attributed to the minimum residual influence of shallow or minimum tillages on the succeeding maize crop growth and yield. These results agree with those of previous studies by Legere and Sampson (1999) and Donovan and Mc Andrew (2000) who have reported lesser yields of barely with long term zero and conservation tillages due to unchecked weed competition on crop productivity.

Higher grain (5348kg/ha) and stover (9800 kg/ha) yields of maize recorded with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (W_2), could be attributed to the reason that herbicide application might have killed the weeds at earlier germination phase devoiding competition for crop growth from the inception of germination of the crop and manual removal on 20 DAS lasting its efficiency at later growth stages. The results are in accordance with the reports of Saikia and Pandey (1999) which highlighted the advantages of atrazine as well as manual weeding on the maize yields by their better weed control efficiencies. Similarly, hand weeding (W_1) and mechanical weeding with rotary weeder twice (W_3) on 20 and 40 DAS, also resulted in comparable yields of grain and stover with that of herbicidal + manual weeding (W_2) in maize. Higher weed control efficiency and lower depletion of nutrients by weeds might have promoted the growth and development of maize, consequently favouring higher yields of grain and stover. Nearly 42% yield reduction was noticed under unweeded control (W_4), which might be due to the increased magnitude of weed competition with unchecked weed growth during both the crop seasons (sunflower and maize). These results are in conformity with the findings of Yadav *et al.* (1985) and Rout and Satapathy (1996), who had reported higher grain yield of maize with pre-emergence application of atrazine which reduced weed competition, from the early growth stages of maize.

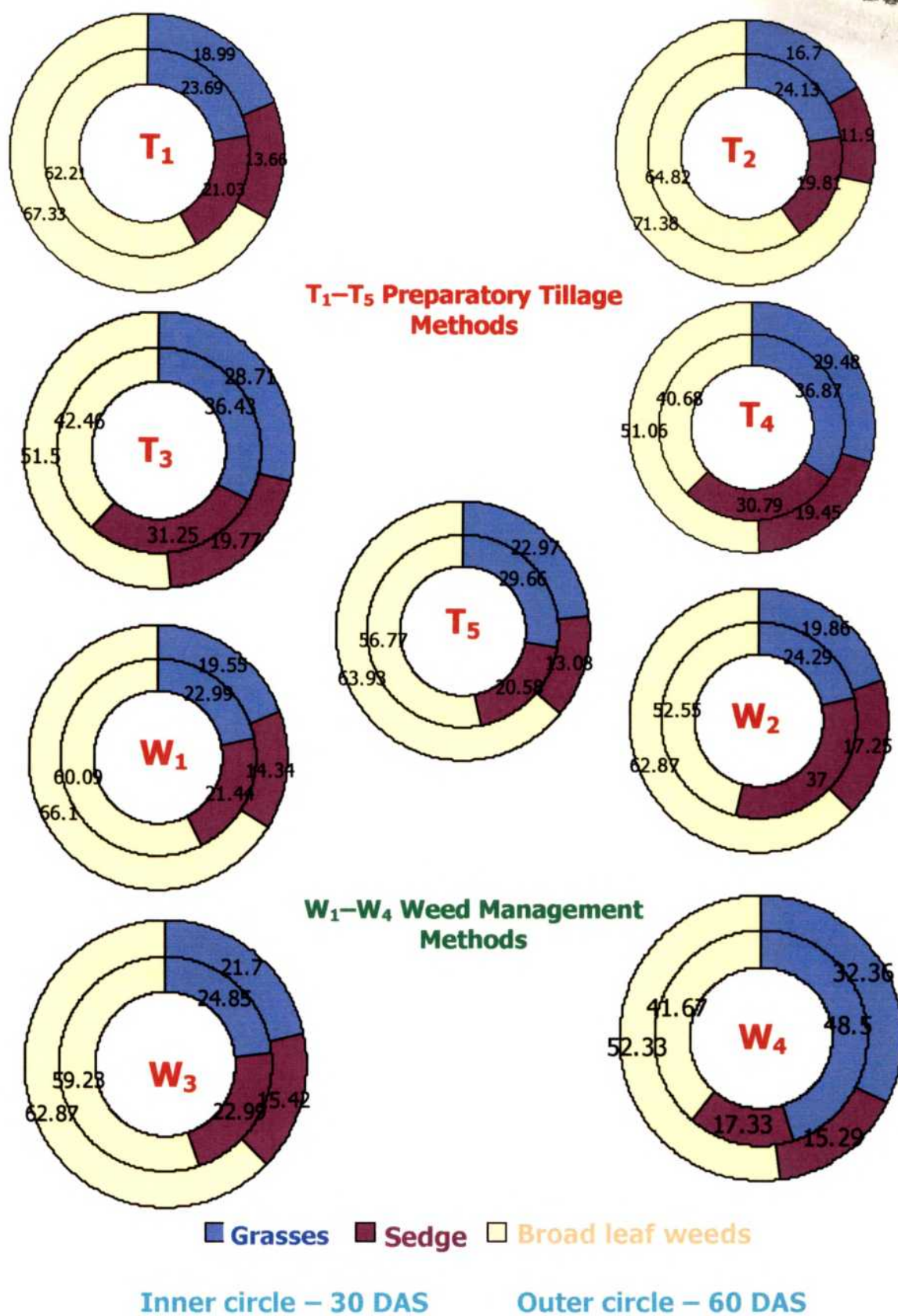


Fig 8. Relative density group wise as influenced by preparatory tillage and weed management methods in maize

5.2.2. Crop growth and physiological attributes

Growth attributes like plant height, dry matter production and leaf area development are the reflective processes of effective utilization of resources in a better crop production environment. Conducive crop growth environment with minimum stresses due to biotic factors like lesser weed competition reflects further on better yield attributes of crops. Dramatic variations in growth and yield attributes of sunflower-maize crops were noticed due to different preparatory tillages and weed management methods primarily associated with change in weed flora composition with varying different weed density and weed dry matter.

Sunflower

Taller plants with broader leaf area might have accumulated higher plant dry matter consistently at all the growth stages of sunflower with preparatory cultivation by disc ploughing followed by cultivator tillage twice (T_4). Better weed control with favourable soil environment might have resulted in reduced crop-weed competition for the growth factors such as light, space and nutrients which in turn helped in efficient photosynthetic activity recording taller plants. Higher competition of early germinated weeds reflected through lesser weed control efficiency with minimum tillage (T_5) might have consequently reduced the required resources availability to crop plants, thus recording reduced plant height to a great extent. In the case of weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (W_2) recorded taller plants and the plants in the unweeded plots (W_4) were obviously shorter than over the hand weeding (W_1) or mechanical weeding twice (W_3). Early control of weeds with herbicidal management and subsequent removal by a hand weeding on 40 DAS might have provided conducive environment for better growth of crop plants as against the faster growth of the weeds in unweeded control causing severe competition from early growth stages for available nutrients between crops and weeds. Similar results were earlier reported by Poonghuzhalan (1992) who have observed that herbicidal and manual weedings recorded

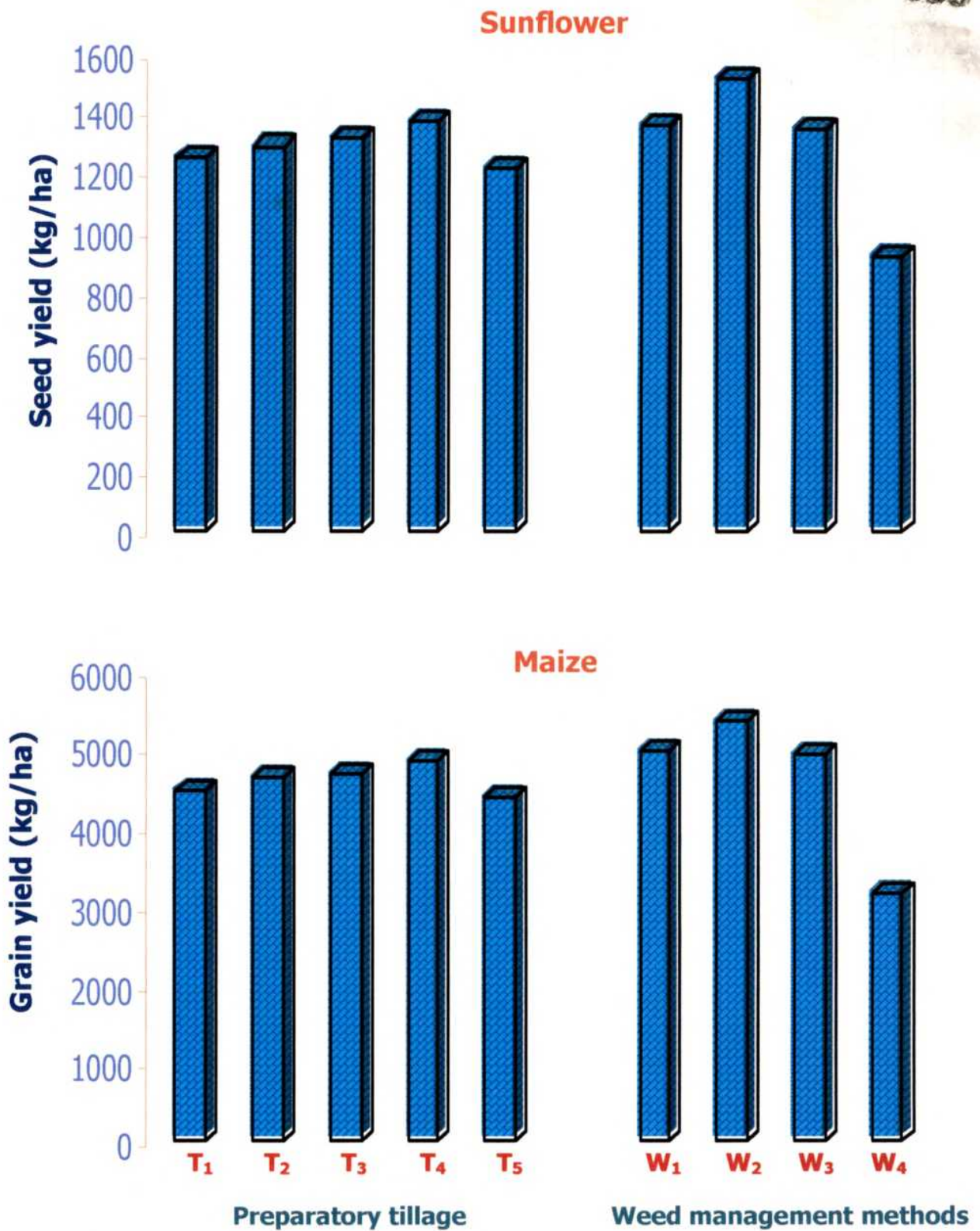


Fig 9. Effect of preparatory tillage and weed management methods on crop yield

taller plants than weedy check due to the reduction in the competition offered by weeds for nutrients and moisture.

Higher plant DMP recorded with deep tillage by disc ploughing followed by cultivator tillage twice (T₄) might be due to higher leaf area, crop growth rate and net assimilation rate which was further reflected through taller plants. Lower weed control efficiency associated with lesser leaf area of the crop, which in turn might have lowered light interception and its efficiency, ultimately reducing the plant dry matter production with minimum tillage (T₅). Higher plant dry matter production recorded with pre-emergence application of pendimethalin 0.05 kg/ha + metolachlor 0.05 kg/ha followed by a hand weeding on 40 DAS (W₂) or with hand weeding (W₁) or mechanical weeding twice (W₃) on 20 and 40 DAS over unweeded control (W₄), might be due to lesser crop-weed competition, at early crop growth stages resulting in higher availability of plant nutrients and moisture. Further, early weed control with herbicidal or manual and mechanical means recorded taller plants with higher leaf area recording better crop growth rates might have contributed for dry matter accumulation due to lesser weed competition. These results corroborates with the findings of Balasubramanian *et al.* (2001) who recorded taller plants with better leaf area and dry matter production in sunflower with weed management by herbicide followed by a hand weeding on 30 DAS.

Physiological parameters such as leaf area index, crop growth rate, relative growth rate and net assimilation rate were also higher with disc ploughing followed by cultivator tillage twice (T₄) due to lesser competition offered by weeds for light, space and nutrients which has also reflected in improved plant DMP and consequently on crop yield. Minimum tillage (T₅) resulted in lower physiological parameters might be due to higher crop-weed competition.

Early weed control by pre-emergence application of pendimethalin 0.05 kg/ha + metolachlor 0.05 kg/ha followed by a hand weeding on 40 DAS (W₂) helped in recording higher leaf area index, crop growth rate, relative growth rate and net assimilation rate might be probably due to higher weed control efficiency which in turn might have improved the availability of light and nutrients for crop growth. The results corroborate

Effective control of weeds with herbicide



Profused weed growth with unweeded control



Plate 10. Influence of mould board tillage on weed population with atrazine and unweeded control in succeeding

with the findings of Jat and Giri (2000) who have reported maximum leaf area with better crop growth rates by application of pendimethalin as a result of most effective weed control resulting in better energy harvest of sunflower unweeded control (W_4) obviously resulted in lower physiological parameters, which were further associated with growth and yield attributes due to severe weed competition through out the crop growth period.

Maize

Preparatory cultivation with disc ploughing followed by cultivator tillage twice (T_4) for preceding sunflower crop resulted in taller plants of succeeding maize. Better crop growth with this deep tillage method might be due to reduced growth and density of annual seed germinated weeds associated with higher weed control efficiency. Similar improvement in corn growth in terms of plant height due to reduced annual weed densities with mould board tillage was earlier observed by Buhler and Daniel (1988) and Buhler (1992) in loamy soils. Whereas, minimum tillage (T_5) for the preceding sunflower reflected its poor efficiency by recording shorter plants of succeeding maize, among different tillage methods. High competition of weeds due to undisturbed soil environment might have reduced the input availability to crop plants and might have inturn reduced the plant height, a parameter of growth which is mainly governed by the factors *viz.*, light, space and nutrient availability.

Effective weed control with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (W_2) resulted in taller plants due to good control of dicot and monocot weeds resulting in reduced weed competition for crop growth from germination stage (Plate 10). Either manual weeding (W_1) or mechanical weeding with rotary weeder (W_3) twice on 20 and 40 DAS resulted in better growth of maize recording comparatively taller plants than unweeded control (W_4). Efficacy of mechanical or manual weeding in controlling the weeds at critical crop-weed competition of 45 DAS in maize might be the reason for better growth of maize in mechanical or manual weeding. These results are in line with the findings of Perron *et al.* (2001) who reported that the efficiency of mechanical weeding could be further enhanced by complementing with other weed control methods.

Effective control of weeds with herbicide



Profused weed growth with unweeded control



Plate 11. Influence of minimum tillage on weed population with atrazine and unweeded control in succeeding maize

Higher maize dry matter recorded higher with the preparatory cultivation by disc ploughing followed by cultivator tillage twice (T_4) given during preceding sunflower might probably be due to higher weed control efficiency and lower depletion of nutrients by weeds which might have promoted the growth of the plants by efficient utilization of the inputs available. This is in accordance with the findings of Fandoo and Alamendros (1995) who have reported that conventional deep tillage with mould board ploughing had resulted in higher biomass of barley. Minimum tillage (T_5) recorded lower plant DMP due to increased weed competition as reflected through higher total and dominant weed densities and weed dry matter.

More plant dry matter production with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (W_2) might be due to lesser weed competition, as weeds might have been killed from their germination phase and keeping weeds at lower densities. Increased crop growth measured in terms of crop growth rate, relative growth rate and net assimilation rate might have added to the total plant dry matter yield. Superiority of atrazine based integrated weed management in maize in reducing the weed population and weed dry matter consequently recording higher plant dry matter was earlier reported by Rout and Satapathy (1996) and Sharma *et al.* (1998). Unweeded control (W_4) recorded the poor crop growth rate, relative growth rate and net assimilation rate due to high degree weed competition at all the growth stages of crop which might have reflected in lower plant DMP (Plate 11). In general reduction in nutrient removal by weeds through suitable weed management practices enhanced the nutrient uptake and dry matter production of the crops as earlier recorded by Balasubramanian and Veerabadran (1998).

Lesser weed competition resulting in higher availability of plant nutrients and moisture favouring higher leaf area index and vigorous crop growth recording increased crop growth rate, relative growth rate and net assimilation rate might have resulted in higher physiological parameters of maize with disc ploughing followed by cultivator tillage twice (T_4) for preceding sunflower crop. Effective control of the weeds which resulted in the lower weed competition for the growth factors and efficient utilization of the same by the crop plants with pre-emergence application of atrazine 0.25 kg/ha

followed by a hand weeding on 40 DAS (W_2) might be the probable reasons for higher physiological parameters.

5.2.3. Crop yield attributes

Sunflower

Preparatory cultivation with disc ploughing followed by cultivator tillage twice (T_4) increased the yield attributes such as diameter and weight of the capitulum, number of seeds per capitulum and test weight of sunflower. This might be due to higher weed control efficiency and more amount of nutrient uptake consequently resulting in better related growth attributes such as crop growth rate, relative growth rate, net assimilation rate and plant DMP. Yield attributes of sunflower were at lower range with minimum tillage (T_5) might be due to lesser weed control efficiency and higher weed density and dry matter which might have reduced the nutrient availability and utilization of other growth factors for crop.

Better physiological parameters like NAR and growth attributes like plant height, leaf area and dry matter with pre-emergence application of pendimethalin 0.5 kg /ha + metolachlor 0.50 kg/ha followed by one hand weeding on 40 DAS (W_2) resulted in recording bigger capitulum with more seeds per capitulum and test weight of sunflower. This might probably be due to lesser weed growth with better uptake of nutrients by crop with lesser removal by weeds due to lesser weed competition from early stages of crop growth. The result is in line with the findings of Balyan (1993) and Jat and Giri (2000) who have obtained higher yield consequently recording higher yield contributing parameters with pre-emergence application of pendimethalin in sunflower due to better weed control efficiencies.

Obviously, unweeded control (W_4) resulted in lower yield attributes due to stiff and continuous weed competition from the germination of crops throughout its growing period. Timely weed removal on 20 and 40 DAS with either manual weeding twice (W_1) or mechanical weeding twice with rotary weeder (W_3) might have reduced the magnitude of weed competition on crop growth at critical stages, which are reflected through better

yield attributes of maize. These results corroborate with the observations of Gill and Paul (1984) who reported larger capitulum with more diameter in sunflower crops in the manual weeding plots of sunflower. Whereas, Bedmar *et al.* (1983) obtained reduction in seed number per capitulum with unweeded control as against the observations of Basavarajappa (1992) who had reported that manual, mechanical and herbicidal weed control methods increased the capitulum diameter, test weight, number of seeds per capitulum compared to weedy check because of reduced competition from weeds.

Maize

Yield attributes *viz.*, cob length and girth, grains per cob and test weight of succeeding maize were higher with the preparatory cultivation by disc ploughing followed by cultivator tillage twice (T_4), during the preceding sunflower cropping season. It might be due to better WCE resulting in lower depletion of nutrients by weeds consequently with better uptake of nutrients by maize promoted the yield components.

Higher weed density from the preceding season weed seeds resulting in more total and dominant weed population and higher weed dry matter with minimum tillage (T_5) during preceding sunflower season, might have reduced the growth and physiological attributes consequently recorded poor yield attributes. However, shallow preparatory tillages like country plough (T_1) or cultivator tillage twice (T_2) during sunflower cropping, had also resulted in higher weed competition, consequently recording lesser yield contributing parameters than with deep and inversion tillage systems. These findings are in accordance with results of Burgos and Talbert (1996) and Barberi *et al.* (1998) who had reported the advantages of deep tillage systems on weed seed burial and better yield attributes in continuous maize cropping.

Heavier and longer maize cobs with more number of grains and higher test weight were obtained with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (W_2). It might be due to better control of weeds from its germination phase and providing better scope for enhanced growth and better CGR, RGR and NAR of maize. Manual weeding twice (W_1) or mechanical weeding twice with

rotary weeder (W_3) on 20 and 40 DAS also provided favourable environment for recording higher yield attributes of maize against unweeded control (W_4), which obviously experienced severe weed competition from germination phase to all the crop growth stages. Similar reduction of cob length and girth and grain number per cob were recorded by Beck (1985) and Pandey *et al.* (2001) due to the competition offered by unchecked weeds in between crop plants in unweeded control maize fields.

5.3. Influence of preparatory tillage and weed management methods on the productivity of sunflower-maize cropping system

5.3.1. Maize grain equivalent yield

The yields of component individual crops in the sequential cropping and their system productivity are mainly controlled by the manipulations of cropping environment, crop rotation, land preparation and weed management methods. Among the primary environmental manipulations, management of weeds with integrated effort of preparatory tillage associated with different weed management methods, form a vital input management system for higher yields of individual crops as well as the system productivity.

Productivity of sunflower-maize cropping system was obtained by converting both the crop yields into a single crop equivalent yield obtained on the basis of market cost price of yields. Hence, maize grain equivalent yield was obtained to assess the influence of preparatory tillage and weed management methods on the system productivity.

Higher maize grain equivalent yield of (7104 kg/ha) of sunflower-maize cropping system was obtained with preparatory cultivation by disc ploughing followed by cultivator tillage twice (T_4) during the preceding sunflower crop period (fig 10.). This is due to the better performance of both the crops in the sunflower-maize system as a result of favourable soil conditions in terms of pulverisation and inversion by deep tillage methods favouring lesser weed competition and better sunflower growth and yield and its long term effect reflected through higher grain yields of maize in the system. Deep tillage

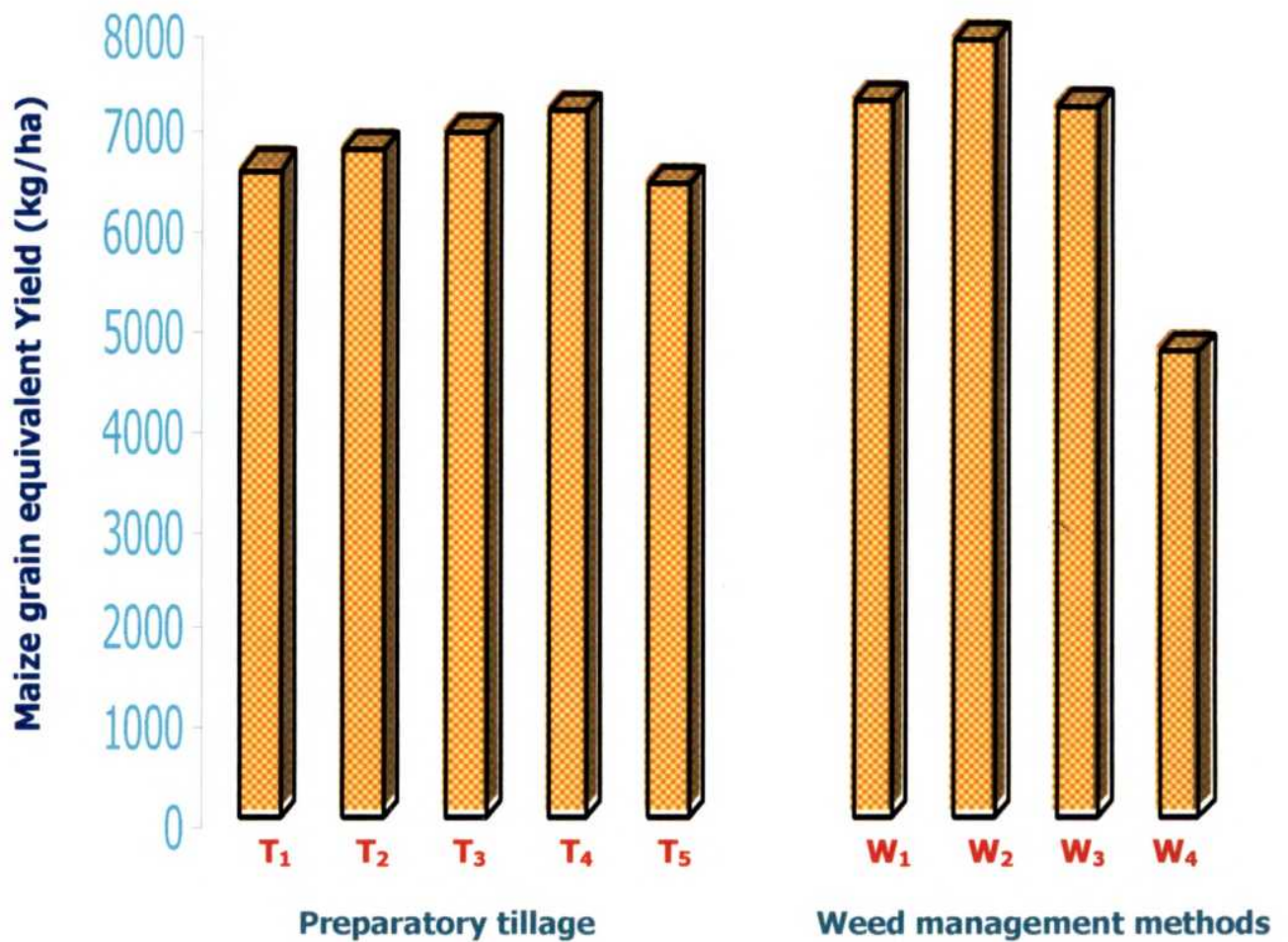


Fig 10. System productivity as influenced by preparatory tillage and weed management methods in sunflower-maize cropping system.

with mould board ploughing followed by a cultivator tillage (T_3) also had comparable maize grain equivalent yield (6870 kg/ha) of the system, reflecting its efficiency as that of deep disc ploughing followed by cultivator tillage. Minimum tillage (T_5) recorded the lowest system productivity which might be due to higher weed infestation which reflected in the form of increased weed dry matter and lesser crop growth and yield parameters. Even shallow tillage with either country plough (T_1) or cultivator tillage twice (T_2) proved its superiority than minimum tillage in recording better maize grain equivalent yields of the sunflower-maize system.

Integrated weed management with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2) for the respective crops in the sunflower-maize cropping recorded the highest maize grain equivalent yield of 7867 kg/ha, reflecting the highest weed control efficiency consequently favouring higher yields of individual crops as well as the sunflower-maize cropping system. This might be due to lesser crop-weed competition with herbicide treated plots which might have effectively utilized the available light, nutrients and moisture recording higher plant DMP which ultimately reflected in the productivity of the system. Obviously, unweeded control (W_4) in both the crops recording the lowest grain yields of individual crops as a result of continuous weed competition in both crops, might have resulted in the lowest system productivity of 4684 kg/ha maize grain equivalent yields.

Consistent increase of plant dry matter production at all the growth stages of both the crops reflected in the system plant dry matter production with deep tillage by disc or mould board ploughing followed by cultivator tillage twice (T_4 or T_3) during initial period of sunflower-maize cropping system. Similarly, the consistent efficiency of integrated weed management with herbicide + hand weeding (W_2) in both the crops for effective long-term weed control resulted with higher plant dry matter of sunflower-maize cropping (Fig 11.).

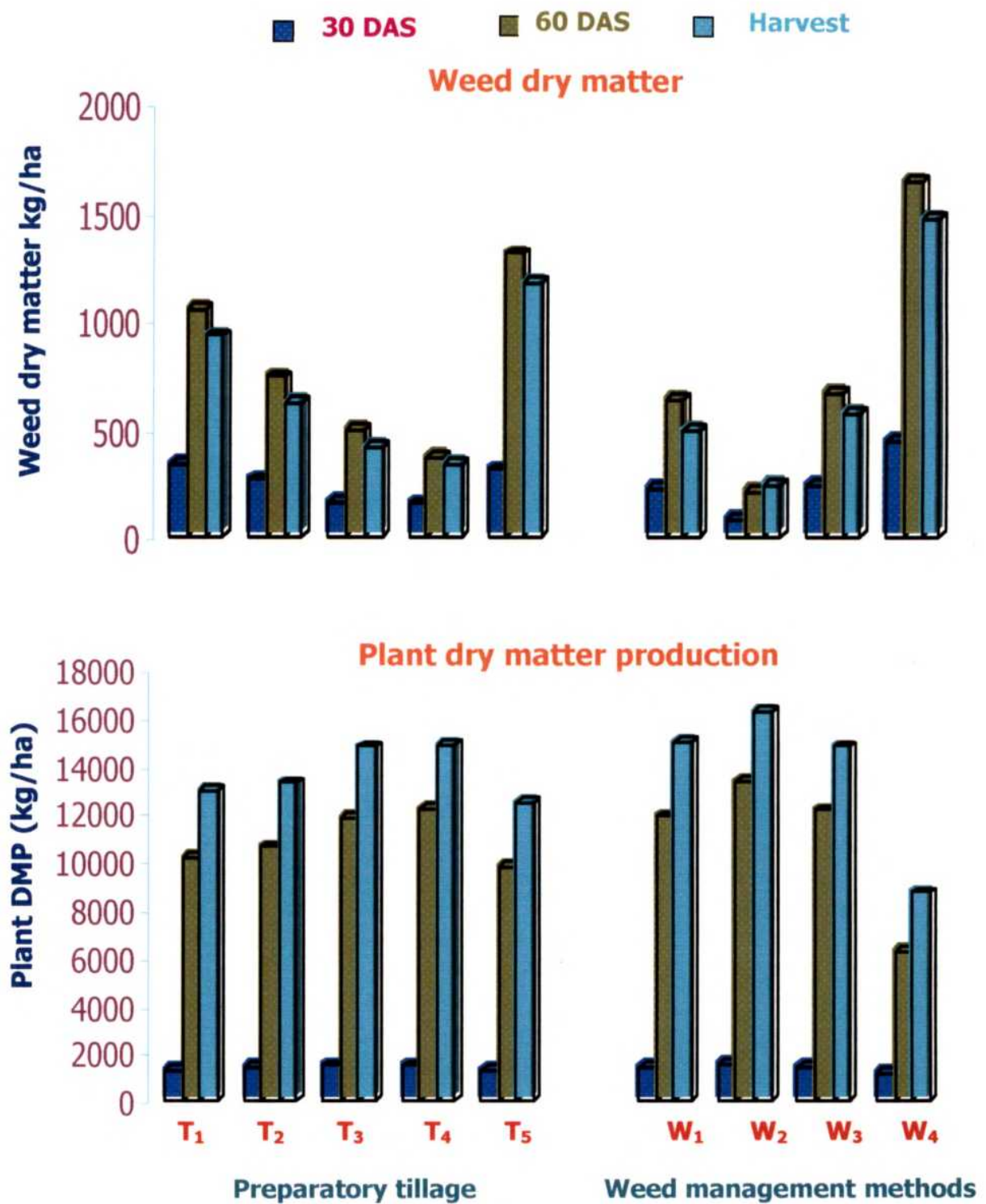


Fig 11. Weed and plant DMP as influenced by preparatory tillage and weed management methods in sunflower- maize cropping system

5.3.2. Weed parameters

Total weed dry matter at three different growth stages of each crop in sunflower-maize cropping system, was obtained to identify the influence of preparatory tillage and weed management methods. Lowest weed dry matter was recorded by disc or mould board ploughing followed by cultivator tillage twice (T_4 or T_3) which might be due to lower nutrients uptake by weeds resulting with lesser total and dominant weed densities reflecting in reduced competition between crops and weeds for growth factors. Minimum tillage (T_5) increased the total weed dry matter of the sunflower-maize cropping system, might be due to higher weed infestation at all growth stages of both the crops. Lower weed index is the reflective factor of higher weed control efficiency which was recorded with deep and inversion tillage by disc ploughing followed by cultivator tillage (T_4) because of higher productivity of the system as a whole.

Integrated weed management with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2) in the individual crops reduced the total weed dry matter (Fig 11.) which might probably be due to effective control of predominant seed germinated weeds and increased efficiency of crop plants in utilizing the available nutrients, light and moisture. Unweeded control (W_4) obviously recorded the highest weed index which was reflected form the lower system productivity.

5.4. Influence of preparatory tillage and weed management methods on the nutrients uptake by crops and removal by weeds

Weeds being a serious negative factor in the crop production are responsible for marked losses of crop yields. Weeds that grow with crop plants deplete considerable amount of costly fertilizer nutrients in addition to available soil moisture. The extent of nutrients loss varies from 30 to 40% of the applied nutrients depending upon the weed flora composition and time and method of weed management. Effective weed control by different methods to provide a conducive environment for increased uptake of nutrients by crop with proportionate decrease in the depletion of nutrients by weeds.

5.4.1. Nutrients uptake by crops

Quantity of nutrients uptake by crops is the reflection of crop biomass and nutrient content at each growth stage. Preparatory tillage with disc (T₄) or mould board ploughing (T₃) followed by cultivator tillage twice at the beginning of sunflower-maize cropping resulted in higher nutrient uptake by both the crop plants, as the deep ploughing might have facilitated the better root development of the crop plants helped in the comfortable establishment of the crops and burial of the weed seed resulting in the lesser weed competition for a longer cropping period. Deep ploughing followed by cultivator tillage practices reduced the nutrient depletion by weeds consequently increased N, P and K uptake in wheat as observed by Pandey *et al.* (2001a). Higher N, P and K uptake by both the crops with herbicidal + manual weeding (W₂) could be attributed mainly to the higher plant dry matter recorded consequently at different growth stages. Minimum tillage (T₃) recorded the lowest nutrient uptake due to lower WCE reflected with lesser plant dry matter production.

Integrated weed management by pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W₂) for each crop resulted in higher plant dry matter and consequently highest N, P and K nutrients uptake by the plants. Obviously, unweeded control (W₄) in both the crops resulted in lesser plant dry matter in turn recording the least nutrient uptake by both the sunflower and maize plants. Better weed control efficiency associated with herbicidal + manual weeding in both the crops might have favoured vigorous growth of plants, higher plant dry matter with uptake of more amounts of nutrients by sunflower and maize crops. Whereas in unweeded control (W₄) of both the crops in sunflower-maize cropping recorded the least nutrients uptake by the plants might be due to maximum utilization of resources by weeds rather than crops, as a result of high degree of weed competition. Similar results were earlier reported by Girijesh and Patil (1989) and Malpatil and Patil (1990) who stated that, in the absence of higher weed competition, sunflower made the fullest use of nutrients and hence nutrient uptake by the crop was maximum in the herbicide + manual weeding methods.

5.4.2. Nutrient removal by weeds

Weed densities and proportionate biomass production by individual weeds constitute the total weed dry matter, which in turn with its nutrient contents decide the amount of nutrient depletion by weeds. Minimum tillage (T_5) recorded the highest N, P and K nutrients removal by weeds as it had recorded the highest weed dry matter due to heavy crop-weed competition. However the lowest N, P and K nutrients removal by weeds with deep tillage systems by disc (T_4) or mould board ploughing (T_3) followed by cultivator tillage twice to the beginning of sunflower-maize cropping system. Lower total weed dry matter with deep tillage systems might have reduced the nutrient removal by weeds as obtained by Pandey *et al.* (2001a) with wheat in clay loam soils.

Integrated weed management by pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by manual weeding on 40 DAS (W_2) in each crop individually reduced the nutrients removal by weeds due to lesser total weed density and weed dry weight with higher WCE. This is in line with the findings of Rathi and Tiwari (1981); Azad (1997) and Pandey *et al.* (2001a) who had recorded lesser nutrient depletion by weeds with herbicidal as well as manual weedings in wheat against unweeded control. Higher nutrients removal by weeds were recorded obviously with unweeded control (W_4) in both the crops due to higher total densities and more dry matter of weeds because of the early emergence, faster and continuous unchecked growth of weeds through out the crop growth period, which might have depleted the nutrients earlier than the crop plants. This might probably be due to the severe competitive ability of weeds for the resources like nutrients, moisture and the space against crop plants.

5.5. Influence of preparatory tillage and weed management methods on the economic efficiency

Economic efficiency and viability of crop cultivation are mainly the outcome of yield of crops with larger input management costs. Higher crop productivity with lesser cost of cultivation could result in better economic parameters like higher net returns, B:C ratio and per day returns.

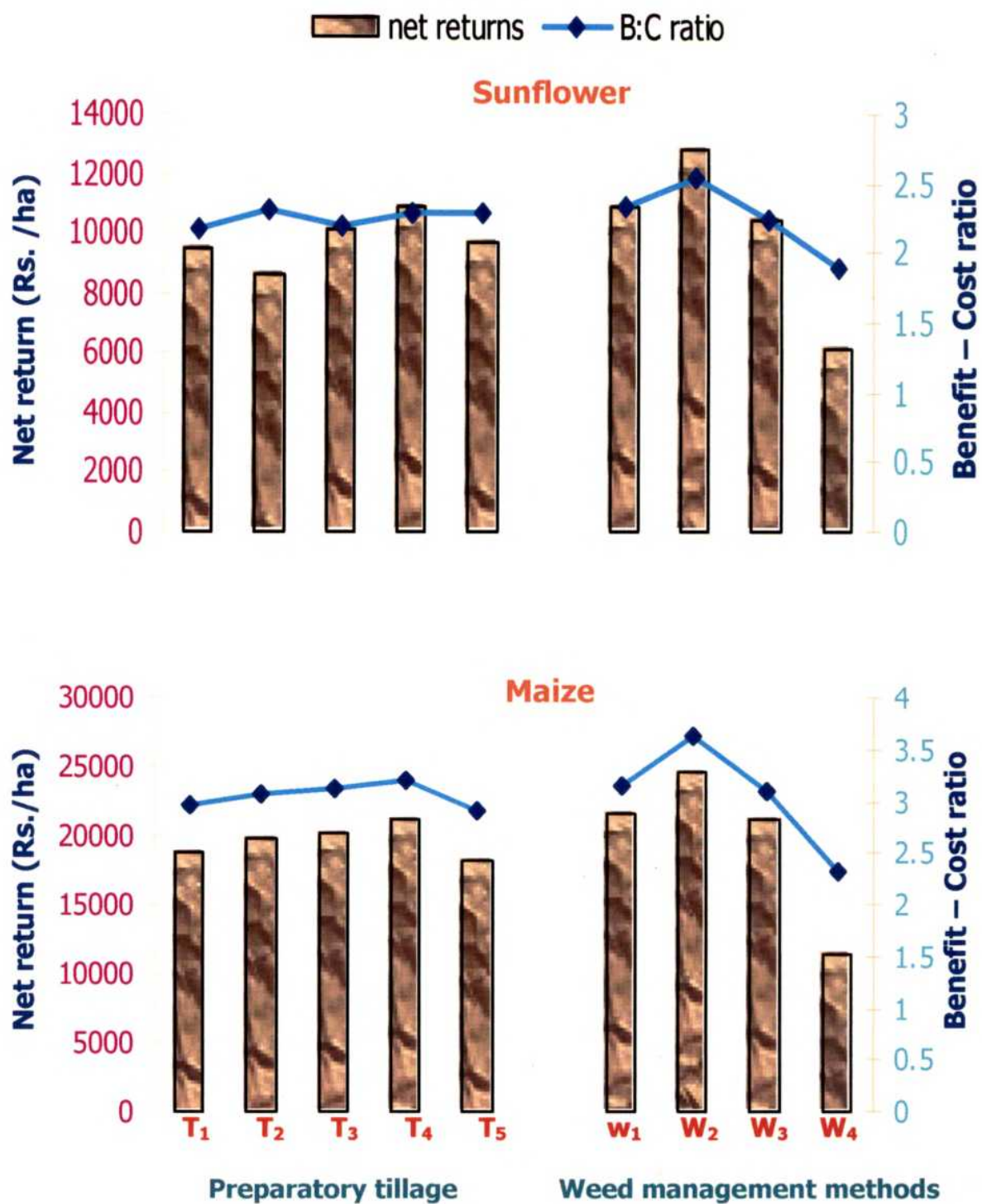


Fig 12. Net returns and B: C ratio as influenced by preparatory tillage and weed management methods in sunflower-maize cropping system

5.5.1. Individual crops

Sunflower

The highest economic returns such as gross and net returns of Rs. 21,364/ha and Rs. 12,681/ha, respectively, were obtained with preparatory tillage by disc ploughing followed by cultivator tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (T₄W₂), obviously due to higher yield obtained because of effective weed control reflected through better crop growth. Highest return of Rs. 2.70 could be obtained with minimum tillage coupled with pre-emergence weed management by pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (T₅W₂) for every rupee invested on cost of cultivation might be due to lesser costs involved in land preparation and effective weed control by herbicide + manual weeding. In addition a net return of Rs.147/day could also be obtained indicating its economic efficiency. Deep or shallow preparatory tillages combined with either hand weeding twice or mechanical weeding twice registered lesser monetary benefits than the combination of herbicidal + manual weed management with any of the preparatory tillage methods due to higher costs of weeding with either manual or mechanical methods. This result is in line with the findings of Cox *et al.* (1999) who had reported that use of mould board plough tillage with mechanical weed management could result in higher net returns in soybean.

Maize

Preparatory tillage with disc ploughing followed by cultivator tillage for preceding sunflower combined with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (T₄W₂) for maize in sunflower-maize cropping, resulted in the highest returns of Rs. 34,306/ha and net returns of Rs. 24,938/ha with maize. A return of Rs. 3.66 for every rupee invested on cost of cultivation and per day income of Rs. 237/ha could be obtained because of highest yields due to early and efficient weed control. Minimum tillage to preceding sunflower coupled with pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS (T₅W₂) resulted in the lowest gross and net returns, B:C ratio and per day returns (Rs.

18,045/ha, Rs. 9,485/ha, 2.10 and Rs. 90/ha, respectively) due to lesser yields of grain and stover because of continuous heavy weed competition in maize as well as the preceding sunflower in the sunflower-maize cropping system. These results are in accordance with the findings of Cox *et al.* (1999) who had obtained lesser net returns with mechanical weeding combined with chisel tillage in maize.

5.5.2. Cropping system economic efficiency

System economic efficiency was analysed based on the cost of cultivation for both the crops with their gross returns. Economic parameters like gross returns, net returns, B:C ratio and per day returns were influenced by the preparatory tillage and weed management methods. Highest gross returns of Rs. 47,658/ha was obtained with preparatory tillage by disc ploughing followed by a cultivator tillage twice for first crop of sunflower combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (T₄W₂) in sunflower-maize cropping system as it had recorded the highest system productivity as maize grain equivalent yield. Cultivator tillage twice for preceding sunflower combined with pre-emergence herbicides application followed by a hand weeding (T₂W₂) resulted in the highest net returns of Rs. 29,922/ha (Fig 12.) and higher per day returns of Rs. 155/ha due to lesser cost of cultivation and higher yields of grain as well as stover. Highest B:C ratio of 2.73 was obtained with minimum tillage for sunflower crop alone combined with pre-emergence herbicide application followed by a hand weeding on 40 DAS (T₅W₂) for both the crops, because of lower cost of cultivation involved in land preparation coupled with higher yields due to efficient weed control by the herbicides and manual weeding.

SUMMARY AND CONCLUSION

CHAPTER VI

SUMMARY AND CONCLUSION

Tillage or soil surface manipulation to obtain desired seedbed is a major input in agricultural production. Weeds cause greater loss to crop yields, among the total production losses and weeds alone constitute 33% share. Tillage helps in controlling weeds by killing emerging seedlings, burying seeds, delaying growth of perennials, providing a rough surface which hinders seed germination, providing loose surface soil, which permits effective cultivation, providing a clean uniform surface for efficient action of herbicides and incorporation of herbicides when necessary. Being wider spaced row crops, having slow initial growth, sunflower and maize heavily suffer from weed competition. The optimum tillage practice combined with the effective weed control method is to be identified for the efficient weed management in the system as a whole for sunflower-maize cropping sequence. Hence, a field experiment was conducted during *kharif-rabi* seasons of 2001-2002 at Eastern Block Farm, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, to evaluate the influence of preparatory tillages and weed management methods on weed dynamics and crop productivity of sunflower- maize cropping system under irrigated condition.

Field experiment was laid out in strip plot design with three replications. Main plot treatments consisted of five different preparatory tillage methods namely two deep tillages (disc or mould board ploughing followed by cultivator tillage twice), two shallow tillages (country plough or cultivator tillage twice) and a minimum tillage with out any preparatory tillage for sunflower crop alone in sunflower-maize cropping system. Three weed management methods *viz.*, pre-emergence herbicide (pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize) application followed by hand weeding on 40 DAS, manual weeding twice or mechanical weeding twice with a rotary weeder on 20 and 40 DAS along with an unweeded check for both the crops consisted the sub plot treatments. Observations were recorded on weed characters like weed flora, weed density and weed dry matter and crop parameters like plant height, dry matter production, leaf area along with physiological and growth parameters and

yield attributes. Grain yields of both the crops and stover yield of maize were weighed to assess the crop productivity. Nutrient uptake by crops and removal by weeds as well as economic aspects like gross and net returns, benefit-cost ratio, per day return were also estimated to record the influence of preparatory tillage and weed management methods. The important findings are summarised and conclusions and recommendations are as follows.

6.1. SUMMARY

The weed flora of the experimental field consisted of fifteen species of predominant weeds. Out of ten broad-leaved weeds, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvenesis* were the dominant ones. *Cynodon dactylon* and *Dactyloctenium aegyptium* among grasses and the sedge *Cyperus rotundus* were also the dominant weeds in both the crops.

The population of grassy weeds such as *Cynodon dactylon*, *Dactyloctenium aegyptium*, sedge *Cyperus rotundus* were reduced with preparatory tillage by country plough (T_1) or cultivator tillage twice (T_2). Preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) for the preceding sunflower crop reduced the population of broad-leaved weeds such as *Parthenium hysterophorus*, *Trianthema portulacastrum*, and *Digera arvenesis* in both sunflower and succeeding maize crops. The population of *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Cyperus rotundus*, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* were significantly reduced with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2). Combination of herbicidal weed management with preparatory tillage by cultivator twice (T_2W_2) reduced the sedge weed density, where as broad-leaved weed density was significantly reduced by the combination of herbicidal weed management with preparatory tillage by disc ploughing (T_4W_2) followed by cultivator tillage twice during sunflower cropping.

Lowest density of grasses and sedge was recorded with preparatory tillage by country plough tillage (T_1) and cultivator tillage (T_2) twice, while preparatory tillage with disc plough followed by cultivator tillage (T_4) reduced the broad-leaved weed population.

Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W₂) effectively controlled the grass, sedge and broad-leaved weeds.

Among the individual weed species, *Trianthema portulacastrum* was predominant with shallow tillages, deep ploughing resulted in higher proportion of *Cynodon dactylon* and *Cyperus rotundus* and in minimum tillage, the relative proportion of *Cynodon dactylon*, *Trianthema portulacastrum* and *Cyperus rotundus* were comparable. Proportion of *Cyperus rotundus* was higher in pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS and *Cynodon dactylon* was in predominant proportion with unweeded control followed by *Cyperus rotundus* and *Trianthema portulacastrum*.

Higher relative density of broad-leaved weeds was registered with shallow and minimum tillage methods and disc ploughing found to record higher sedge population. Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS recorded higher proportion of sedge in sunflower and pre-emergence application of atrazine 0.25 kg/ha followed by a hand weeding on 40 DAS in maize resulted in higher proportion of grasses. In general, relative density of the weeds revealed that, the proportion of both grassy weeds and sedge were reduced as the growth stages advanced from 30 DAS, whereas, the proportion of broad-leaved weeds increased from 30 DAS to later growth stages, irrespective of preparatory tillages and weed management methods.

Preparatory tillage with both disc ploughing (T₄) and mould board ploughing (T₃) followed by cultivator tillage twice recorded the lowest weed dry matter and higher weed control efficiency. Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.50 kg/ha for maize followed by a hand weeding on 40 DAS (W₂) reduced the weed dry matter and the highest weed dry matter was recorded with unweeded control.

Significant improvement in plant growth characters like plant height, DMP, Physiological attributes such as CGR, RGR and NAR, yield attributes like diameter of the

capitulum, capitulum weight, number of seeds and test weight of sunflower and length, girth and weight of the cob, number of grains per cob and test weight of maize was obtained in preparatory tillage with disc plough followed by cultivator tillage twice (T_4). Among the weed management methods, pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2) performed better by improving the growth and physiological parameters and yield attributes of both the crops.

Higher seed yield of sunflower, higher grain and stover yields of maize were obtained by preparatory tillage with disc ploughing followed by cultivator tillage twice (T_4) and minimum tillage (T_5) resulted in lower yields of both the crops. Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2) significantly increased the seed yield of sunflower and grain and stover yields of maize.

Nutrient removal was lower by weeds in preparatory tillage with disc ploughing followed by cultivator tillage (T_4) and minimum tillage (T_5) recorded the highest removal of N, P and K by the weeds. Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_2) significantly lowered the nutrient removal by weeds.

The uptake of nutrients by the crops was higher with preparatory tillage by disc ploughing followed by cultivator tillage (T_4). Mould board ploughing followed by cultivator tillage (T_3) also registered the increased nutrients uptake. Among the weed management methods increased nutrient uptake by crop plants was observed with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS.

Higher weed control efficiency and lower weed index were found in preparatory tillage with disc ploughing followed by cultivator tillage (T_4), which was closely followed by mould board ploughing followed by cultivator tillage twice (T_3) for both sunflower and maize. Pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40

DAS (W_2) recorded higher WCE among the weed management methods. Weed index was lower in both hand weeding (W_1) and mechanical weeding with rotary weeder (W_3) twice on 20 and 40 DAS over the unweeded control.

Highest gross and net returns of Rs.21,364 /ha, and Rs.12,681 / ha were obtained with preparatory tillage by disc ploughing followed by cultivator tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (T_2W_2) in sunflower. Highest return Rs. 2.70 was obtained for every rupee invested on cost of cultivation and higher net return of Rs.147/day was obtained with minimum tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha followed by a hand weeding on 40 DAS (T_5W_2). Minimum tillage combined with unweeded check (T_5W_4) recorded lesser gross (Rs.11,500/ha), net (Rs.5,310/ha) returns, B:C ratio (1.85) and lower per day return of Rs.59/ha for sunflower. Preparatory tillage with disc ploughing followed by cultivator tillage twice to the preceding sunflower combined with pre-emergence application of atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (T_4W_2) resulted in higher gross (Rs.34,306/ha), net (Rs.24,938/ha) returns, B:C ratio of 3.66 and higher per day return of Rs.237/ha.

Preparatory tillage with disc plough followed by cultivator tillage twice (T_4) for preceding sunflower crop in sunflower-maize cropping resulted in lower total weed dry matter of the system. Highest weed dry matter was registered with minimum tillage (T_5) at all the growth stages. Higher plant DMP of the system was recorded in preparatory tillage with mould board ploughing followed by cultivator tillage twice (T_3), which was comparable with disc ploughing followed by cultivator tillage twice (T_4). Lowest weed dry matter and higher plant DMP were obtained with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (W_4) for the system.

Higher maize grain equivalent yield of the system was recorded (7104 kg/ha) with preparatory tillage by disc ploughing followed by cultivator tillage twice (T_4) to sunflower-maize cropping system. Minimum tillage (T_5) registered the lowest productivity (6398 kg/ha) of the system. Higher system productivity of 7867 kg/ha of

maize grain equivalent yield was obtained with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS.

Preparatory tillage with disc ploughing followed by cultivator tillage twice (T4) for preceding sunflower crop alone resulted in lower weed index of the system. Hand weeding twice (W1) and mechanical weeding twice (W3) on 20 and 40 DAS were comparable and recorded lower weed index over the higher weed index in unweeded control (W4).

Higher gross returns of Rs.47,678/ha was obtained with preparatory tillage by disc ploughing followed by cultivator tillage twice for the preceding sunflower crop combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (T4W2). Preparatory tillage with cultivator twice combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (T2W2) resulted in higher net returns of Rs.29,922/ha and higher per day returns of Rs.155/ha. Preparatory cultivation with minimum tillage combined with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by a hand weeding on 40 DAS (T5W2) recorded higher benefit-cost ratio of 2.73 for the system.

6.2. CONCLUSIONS

The following conclusions are drawn from the results of the field experiments

- ☐ Grassy weeds, *Cynodon dactylon*, *Dactyloctenium aegyptium*, the only sedge *Cyperus rotundus* and broad-leaved weeds, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Digera arvensis* were the predominant weed flora of the experimental field.
- ☐ Grassy weed density was reduced and the broad-leaved weed population was increased with higher weed dry matter in shallow tillages. Deep tillages recorded lower broad-leaved weed population and higher grassy weed growth.

Deep preparatory tillages in combination with herbicidal + manual weeding with deep tillages reduced the weed density considerably.

- ☐ Growth attributes such as plant height, plant DMP, physiological parameters like CGR, RGR, NAR, yield attributes such as diameter of the capitulum, weight of the capitulum, number of seeds per capitulum and test weight in sunflower and length, girth and weight of cob, test weight and number of grain per cob in maize were recorded higher with disc ploughing followed by cultivator tillage twice. Pre-emergence application of herbicide mixture of pendimethalin 0.50 kg/ha + metolachlor 0.50kg/ha for sunflower and atrazine 0.25 kg/ha for maize performed better by increasing the growth attributes, physiological parameters and yield attributes.
- ☐ Deep preparatory tillage, integrated with herbicide + manual weeding resulted in increased seed yield of sunflower, grain and stover yields of maize.
- ☐ Preparatory tillage with disc ploughing followed by cultivator tillage resulted in higher WCE and reduced WI. Hand weeding and mechanical weeding twice were comparable in recording lesser WI over the unweeded control. Herbicidal + manual weeding resulted in higher WCE among the weed management methods.
- ☐ Deep tillages resulted in higher nutrient uptake by crop plants and lower removal by weeds. Pre-emergence herbicide application followed by manual weeding significantly reduced the nutrient removal by weeds and increased the plant nutrient uptake.
- ☐ Higher gross and net returns were obtained in preparatory tillage with disc plough combined with application of pre-emergence herbicide followed by manual weeding, whereas higher returns per rupee invested and higher per day returns were resulted with minimum tillage combined with herbicide application followed by manual weeding in sunflower. But in maize all the economic indices such as higher gross, net returns, B:C ratio and per day returns were found with deep tillage combined with integrated herbicide + manual weeding.

- ☐ Higher grain equivalent yield of the system was obtained with disc ploughing followed by cultivator tillage among the preparatory tillage methods and herbicide followed by manual weeding in case of weed management methods.
- ☐ Cultivator tillage combined with integrated management of herbicide + manual weeding found to result in the highest net returns and per day returns for the system, whereas higher income per rupee invested was obtained with minimum tillage combined with herbicidal + manual weeding.

6.3. RECOMMENDATION

From the results of the field experiment, it could be concluded that preparatory tillage with disc plough followed by cultivator tillage twice for preceding sunflower with pre-emergence application of pendimethalin 0.50 kg/ha + metolachlor 0.50 kg/ha for sunflower and atrazine 0.25 kg/ha for maize followed by one hand weeding on 40 DAS can keep the weed density and weed dry matter below the economic threshold level and increase the productivity and profitability of sunflower-maize cropping in the Western zone of Tamil Nadu. Minimum tillage combined with herbicide + manual weeding could be adopted as suitable tillage and weed management methods to obtain higher economic returns per rupee invested on cost of cultivation with better per day returns in sunflower-maize cropping system.

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*** Originals not seen**

APPENDICES

Appendix I. Weather Parameters during the Cropping (Sunflower-Maize) Period

Standard Weeks	Period	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Evaporation (mm)	Sunshin hours
		Maximum	Minimum	(7.22 hrs)	(14.22 hrs)			
Sunflower								
29	Jul 16-22	31.6	22.1	81	51	0.5	5.8	6.9
30	23-29	31.5	21.3	87	55	9.5	6.1	6.7
31	30-5 Aug	28.7	22	85	67	11.5	3.4	2.2
32	Aug 6-12	31.9	22.1	85	50	0	6.9	7.3
33	13-19	32.2	23	81	49	0.7	7.2	6.1
34	20-26	32.1	22.2	85	51	4	6.4	6
35	27-2 Sep	32.2	21.3	90	49	10.6	5.8	7.1
36	Sep 3-9	33.5	21.2	86	44	0	5.8	10.1
37	10-16	33.6	22.9	90	49	48.6	3.9	7.1
38	17-23	32.9	23.2	87	50	6.5	4.2	5.4
39	24-30	30.9	22.2	92	59	41.5	5.3	4.3
40	Oct 1-7	31.1	22.4	87	58	2	4.5	4.7
41	8-14	31.4	22.7	88	61	0	4.8	4.8
42	15-21	31.7	21.7	93	60	152.3	4.3	6.3
43	22-28	30.3	19.3	92	63	130.4	4.3	5.4
Maize								
44	29-4 Nov	30	21.7	91	60	17.6	4.3	6.3
45	Nov 5-11	30.4	22.2	93	66	30.9	4	5.3
46	12-18	29.6	22.1	91	71	48.5	3.5	4.7
47	19-25	28.3	20.9	92	65	34.1	3.8	7.6
48	26-2 Dec	28.7	20.9	91	56	8.3	3.3	6.9
49	Dec 3-9	28.9	18	92	53	0.5	4.2	8.2
50	10-16	28.6	15.1	90	37	0	4.5	9.7
51	17-23	27.4	19.9	90	70	14.3	2.8	2
52	24-31	28	20.6	90	57	0.5	3.1	6
1	Jan 1-7	29.3	19.9	86	50	0	4.4	7.6
2	8-14	29.7	19.1	88	45	0	3.5	8.3
3	15-21	30.1	17	90	49	0	3.7	9.1
4	22-28	31.7	21	89	54	0	3.7	4.4
5	29-4 Feb	29.7	20	87	56	0	3.5	3.8
6	Feb 5-11	29.8	21	86	53	0	3.5	4.6
7	12-18	32.2	20.2	87	35	0	5	9

Appendix II

Cost and Price of inputs and outputs of the experiment

Particulars	Unit	Cost price (Rs.)
Urea	kg	5.01
Single Super phosphate	kg	3.10
Murate of potash	kg	4.60
Endosulfon	kg	230
Quinolphos	lit	299
Pendimethalin (Stomp 30 EC)	lit	410
Metolachlor (Dual 50 EC)	lit	200
Atrazine (Atvatay 50 WP)	kg	320
Sunflower (seed)	kg	20
Maize (seed)	kg	20
Sunflower (grain)	kg	14
Maize (grain)	kg	6
Maize (stover)	kg	0.24
'A' Type labour	l	54
'B' Type labour	l	45
Country ploughing with pair	Per day of 8 hrs	300
Cost of Tractor for preparatory tillage	hr	200

Appendix III

Calendar of operations for sunflower and maize cropping

Date	Field Operation
19.7.01	Lay out of the experimental field
21.7.01	Preparatory tillage
22.7.01	Formation of ridges and furrows
23.7.01	Basal dressing of N, P and K fertilizers
23.7.01	Sowing of sunflower
23.7.01	Irrigation I
25.7.01	Pre-emergence spray of herbicide mixture
31.7.01	Gap filling
2.8.01	Irrigation II
4.8.01	Thinning
12.8.01	Hand weeding and mechanical weeding
17.8.01	Spray of endosulfon
25.8.01	Irrigation III
2.8.01	Hand weeding and mechanical weeding
7.8.01	Irrigation IV
15.9.01	Irrigation V
21.10.01	Harvest of sunflower

Calender of operations for maize

Date	Field operation
3.11.01	Rectification of ridges and furrows
4.11.01	Basal dressing of $\frac{1}{4}$ N, full dose of P and K fertilizers
4.11.01	Sowing of maize
4.11.01	Irrigation I
6.11.01	Pre-emergence spray of herbicide
11.11.01	Gap filling
12.11.01	Irrigation II
14.11.01	Thinning
24.11.01	Hand weeding and mechanical weeding
27.11.01	Top dressing of $\frac{1}{4}$ dose of N
6.12.01	Spray of Quinolphos 25 EC 1000 ml/ha
8.12.01	Irrigation III
14.12.01	Hand weeding and mechanical weeding
20.12.01	Top dressing of remaining $\frac{1}{4}$ dose of N
22.12.01	Irrigation IV
14.1.02	Irrigation V
1.2.02	Irrigation VI
16.2.02	Harvest of cobs
17.2.02	Harvest of stover