WEED MANAGEMENT IN MAIZE (*Zea mays* L.) USING STRAW MULCH AND HERBICIDES

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
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in
AGRONOMY
(Minor Subject: Agrometeorology)

By
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(L-2016-A-13-M)

Department of Agronomy
College of Agriculture

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CERTIFICATE - I

This is to certify that the thesis entitled **"Weed management in maize (*Zea mays* L.) using straw mulch and herbicides"** submitted for the degree of **Master of Science** in the subject of **Agronomy** (Minor subject: **Agrometeorology**) to the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ramandeep Kaur (L-2016-A-13-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE - II

This is to certify that the thesis entitled, **"Weed management in maize (*Zea mays* L.) using straw mulch and herbicides"** submitted by **Ramandeep Kaur (L-2016-A-13-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science,** in the subject of **Agronomy** (Minor subject: **Agrometeorology**) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same, in collaboration with an external examiner.

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ABSTRACT

The field experiment entitled "Weed management in maize (*Zea mays* L.) using straw mulch and herbicides" was conducted at Students' Research Farm, Department of Agronomy, PAU, Ludhiana and Research Farm, Regional Research Station Gurdaspur (PAU) during *kharif* 2017. The experiment was conducted in a factorial randomized block design with three replications. There were three mulch treatments as first factor (no mulch, paddy straw mulch at 6.25 t ha^{-1} and paddy straw mulch at 9.0 t ha^{-1}) and six weed control treatments were taken as second factor viz. atrazine at 1.0 kg ha^{-1} pre-emergence, atrazine at 0.8 kg ha^{-1} pre-emergence, tembotrione at 0.110 kg ha^{-1} at 20 DAS, tembotrione at 0.088 kg ha^{-1} at 20 DAS, weed free and unweeded check. The major weed flora included *Dactyloctenium aegyptium, Eragrostis tenella, Digitaria sanguinalis, Echinochloa colona, Cynodon dactylon* as grasses, *Trianthema portulacastrum* as broadleaf weed and *Cyperus rotundus* as sedge. Among different mulch treatments, application of paddy straw mulch at 9.0 t ha^{-1} recorded significantly lower density and weed dry matter accumulation of grasses, sedges and broadleaf weeds as compared to paddy straw mulch at 6.25 t ha^{-1} and no mulch treatments. Highest yield attributing characters, grain yield, net returns and benefit cost ratio were recorded with application of paddy straw mulch at 9.0 t ha^{-1} which were significantly higher than application of paddy straw mulch at 6.25 t ha^{-1} and no mulch treatment. Also, application of paddy straw mulch at 6.25 t ha^{-1} produced significantly higher growth and yield attributes of maize as compared to no mulch treatment. Among the herbicide treatments, tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} were found very effective in controlling different weed species as compared to atrazine at 0.8 kg ha^{-1} and atrazine at 1.0 kg ha^{-1}. Application of tembotrione at 0.088 or 0.110 kg ha^{-1} in combination with straw mulch at 9.0 t ha^{-1} recorded significantly lower density and dry matter accumulation of all weed species but resulted in significantly higher yield attributing characters, grain yield, net returns and benefit cost ratio as compared to all other combinations of straw mulch and herbicides. Thus, for getting higher productivity and profitability from maize, tembotrione at 0.088 kg ha^{-1} as post-emergence in combination with paddy straw mulch at 9.0 t ha^{-1} can be applied, as this herbicide-mulch combination helps in reduction of 20% dose of herbicide.

Key words: Maize, straw mulch, herbicides, weed control, yield attributing characters, grain yield

Signature of Major Advisor **Signature of the Student**

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ਖੇਤ ਤਜ਼ਰਬੇ "ਮੱਕੀ (*ਜ਼ੀਆ ਮੇਜ਼* ਐੱਲ.) ਵਿੱਚ ਪਰਾਲੀ ਅਤੇ ਨਦੀਨ ਨਾਸ਼ਕਾਂ ਦੀ ਵਰਤੋਂ ਨਾਲ ਨਦੀਨ ਪ੍ਰਬੰਧ" ਸਿਰਲੇਖ ਅਧੀਨ ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਫ਼ਸਲ ਵਿਗਿਆਨ ਵਿਭਾਗ ਅਤੇ ਖੇਤਰੀ ਖੋਜ ਕੇਂਦਰ, ਗੁਰਦਾਸਪੁਰ (ਪੀ ਏ ਯੂ) ਦੇ ਖੋਜ ਫਾਰਮ ਵਿਖੇ ਸਾਉਣੀ 2017 ਦੌਰਾਨ ਕੀਤੇ ਗਏ। ਤਜ਼ਰਬਿਆਂ ਨੂੰ ਫਕਟੋਰੀਅਲ ਰੈਂਡੋਮਾਈਜ਼ਡ ਬਲਾਕ ਡਿਜ਼ਾਈਨ ਵਿਧੀ ਤਹਿਤ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਇਆ ਗਿਆ। ਅਧਿਐਨ ਦੌਰਾਨ ਤਿੰਨ ਪਰਾਲੀ ਉਪਚਾਰਾਂ ਨੂੰ ਪਹਿਲੇ ਕਾਰਕ ਵਜੋਂ (ਪਰਾਲੀ ਤੋਂ ਬਿਨ੍ਹਾਂ, ਪਰਾਲੀ 6.25 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ, ਪਰਾਲੀ 9.0 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਅਤੇ ਛੇ ਨਦੀਨ ਪ੍ਰਬੰਧ ਉਪਚਾਰਾਂ ਨੂੰ ਦੂਜੇ ਕਾਰਕ (ਐਟਰਾਜੀਨ 1.0 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਬਿਜਾਈ ਸਮੇਂ, ਐਟਰਾਜੀਨ 0.8 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਬਿਜਾਈ ਸਮੇਂ, ਟੈਂਬੋਟਰਾਈਔਨ 0.110 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਬਿਜਾਈ ਤੋਂ 20 ਦਿਨਾਂ ਬਾਅਦ, ਟੈਂਬੋਟਰਾਈਔਨ 0.088 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਬਿਜਾਈ ਤੋਂ 20 ਦਿਨਾਂ ਬਾਅਦ, ਨਦੀਨ-ਮੁਕਤ ਅਤੇ ਨਦੀਨਾਂ-ਸਹਿਤ) ਵਜੋਂ ਲਿਆ ਗਿਆ। ਅਧਿਐਨ ਦੌਰਾਨ, ਮੁੱਖ ਤੌਰ 'ਤੇ ਮਧਾਣਾ, ਚਿੜ੍ਹੀਆਂ ਦਾ ਦਾਣਾ, ਤੱਕੜੀ ਘਾਹ, ਸਵਾਂਕੀ, ਖੱਬਲ ਘਾਹ, ਚੌਪੱਤੀ ਅਤੇ ਮੋਥਾ ਨਦੀਨ ਪਾਏ ਗਏ। ਪਰਾਲੀ ਉਪਚਾਰਾਂ ਵਿੱਚੋਂ, ਪਰਾਲੀ 6.25 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਬਿਨ੍ਹਾਂ ਪਰਾਲੀ ਵਾਲੇ ਉਪਚਾਰਾਂ ਦੇ ਮੁਕਾਬਲੇ ਪਰਾਲੀ 9.0 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਨਾਲ ਘਾਹ, ਮੋਥੇ ਅਤੇ ਚੌੜੇ ਪੱਤਿਆਂ ਵਾਲੇ ਨਦੀਨਾਂ ਦੀ ਘਣਤਾ ਅਤੇ ਸੁੱਕੇ ਮਾਦੇ ਵਿੱਚ ਅਰਥਪੂਰਨ ਕਮੀ ਦੇਖੀ ਗਈ। ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਝਾੜ ਮਾਪਦੰਡ, ਦਾਣਿਆਂ ਦਾ ਝਾੜ, ਸ਼ੁਧ ਲਾਭ ਅਤੇ ਲਾਭ-ਖਰਚਾ ਅਨੁਪਾਤ ਪਰਾਲੀ ਉਪਚਾਰ 9.0 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਨਾਲ ਪ੍ਰਾਪਤ ਹੋਏ, ਜੋ ਕਿ ਪਰਾਲੀ 6.25 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਬਿਨ੍ਹਾਂ ਪਰਾਲੀ ਉਪਚਾਰਾਂ ਤੋਂ ਅਰਥਪੂਰਨ ਵਧੇਰੇ ਸਨ। ਪਰਾਲੀ 6.25 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਨਾਲ ਵੀ ਬਿਨ੍ਹਾਂ ਪਰਾਲੀ ਦੇ ਮੁਕਾਬਲੇ, ਵਿਕਾਸ ਅਤੇ ਝਾੜ ਮਾਪਦੰਡਾਂ ਵਿੱਚ ਅਰਥਪੂਰਨ ਵਾਧਾ ਹੋਇਆ। ਨਦੀਨ ਨਾਸ਼ਕਾਂ ਵਿੱਚੋਂ, ਐਟਰਾਜੀਨ 0.8 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਐਟਰਾਜੀਨ 1.0 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੇ ਮੁਕਾਬਲੇ ਟੈਂਬੋਟਰਾਈਔਨ 0.088 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਟੈਂਬੋਟਰਾਈਔਨ 0.110 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਵੱਖ-ਵੱਖ ਨਦੀਨਾਂ ਦੀ ਰੋਕਥਾਮ ਲਈ ਜ਼ਿਆਦਾ ਅਸਰਮੰਦ ਸਿੱਧ ਹੋਏ। ਪਰਾਲੀ ਅਤੇ ਨਦੀਨ ਪ੍ਰਬੰਧ ਦੇ ਸਾਰੇ ਉਪਚਾਰਾਂ ਦੇ ਸੁਮੇਲਾਂ ਵਿੱਚੋਂ ਟੈਂਬੋਟਰਾਈਔਨ 0.088 ਜਾਂ 0.110 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ, ਪਰਾਲੀ 9.0 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੇ ਸੁਮੇਲ ਨਾਲ ਨਦੀਨਾਂ ਦੀ ਘਣਤਾ ਅਤੇ ਸੁੱਕੇ ਮਾਦੇ ਵਿੱਚ ਅਰਥਪੂਰਨ ਘਾਟਾ ਦੇਖਿਆ ਗਿਆ, ਜਦਕਿ ਝਾੜ ਮਾਪਦੰਡ, ਦਾਣਿਆਂ ਦਾ ਝਾੜ, ਸ਼ੁਧ ਲਾਭ ਅਤੇ ਲਾਭ-ਖਰਚਾ ਅਨੁਪਾਤ ਵਿੱਚ ਅਰਥਪੂਰਨ ਵਾਧਾ ਹੋਇਆ । ਇਸ ਲਈ ਟੈਂਬੋਟਰਾਈਔਨ 0.088 ਕਿਲੋ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਅਤੇ ਪਰਾਲੀ 9.0 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਦੇ ਸੁਮੇਲ ਨਾਲ ਮੱਕੀ ਤੋਂ ਵਧੇਰੇ ਉਤਪਾਦਿਕਤਾ ਅਤੇ ਲਾਭ ਪ੍ਰਾਪਤ ਕੀਤਾ ਜਾ ਸਕਦਾ ਹੈ ਕਿਉਂਕਿ ਇਹ ਸੁਮੇਲ ਨਦੀਨ ਨਾਸ਼ਕ ਦੀ 20 ਪ੍ਰਤੀਸ਼ਤ ਮਾਤਰਾ ਘਟਾਉਣ ਵਿੱਚ ਸਹਾਇਕ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਮੱਕੀ, ਪਰਾਲੀ, ਨਦੀਨ ਨਾਸ਼ਕ, ਨਦੀਨ ਪ੍ਰਬੰਧ, ਝਾੜ ਮਾਪਦੰਡ, ਦਾਣਿਆਂ ਦਾ ਝਾੜ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER I

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop and referred as "queen of cereals" around the world due to high productivity among the cereals. Worldwide, it was cultivated on 185.7 million hectares and recorded the production of 1075.3 million tonnes of grains with an average grain yield of 5.79 tonnes per hectare during 2016-17. In India, maize was cultivated on 7.66 million hectares and recorded the production of 15.5 million tonnes of grains with an average grain yield of 2.56 tonnes per hectare (Anonymous 2017). In Punjab, maize is mainly grown during the *kharif* season and was cultivated on 1.16 lakh hectares with a production of 4.45 lakh tonnes and average yield of 3.84 tonnes per hectare during 2016-17 (Anonymous 2018). Maize is a C_4 plant which is considered to be energy efficient and has high yield potential which also adds towards its importance in agriculture. It contains 10.4% proteins, 4.5% fat, 71.8% starch, 3% fiber along with vitamins and minerals. Its flour is considered a good diet for heart patients due to its low gluten (protein) content (Gul *et al* 2016). It is also used as green fodder at early stages, baby corn at very early cob stage, green cob at late milk to dough stage, maize grains as pop corn and maize flour for chapatti making. Besides this, crop also provides a good quality feed for piggery, poultry and milch animals. Being a versatile food crop of global importance, it is used as a source of raw material for many industrial products for food, animal feed, poultry feed, starch and brewery (Dass *et al* 2008 and Owla *et al* 2015). Due to its unique photosynthetic mechanism, it produces high biological and grain yield in a short span of time.

Maize crop is adapted to the divergent climatic conditions prevailing in the tropical to temperate regions throughout the country especially during *kharif*, *rabi* and spring seasons in Peninsular India, *kharif* and spring seasons of Indo-Gangetic plains and *kharif* season in the hilly areas. The most suitable temperature for the maximum productivity of the crop is 20-27^{0}C but it can also be grown at low temperature of 10^{0}C with a frost free season. There is a lot of scope to increase the present yield level in maize due to its wider soil and climatic adaptability.

In Punjab, the optimum sowing time of *kharif* maize is from last week of May to end of June. This period is characterized by a high evaporative demand due to high temperature and low relative humidity. Among the various factors responsible for low yields in maize, severe infestation of weeds often inflict huge losses in yield, may be up to 52% (Walia *et al* 2005). Due to wider row spacing and co-incidence of crop with rainy season, yield losses in maize ranged from 28-100% attributed to heavy infestation by different weed species and severe crop-weed competition (Patel *et al* 2006). The infestation of weeds like *Acrachne racemosa, Brachiaria reptans* and *Commelina benghalensis* etc. are increasing day by day in the maize growing belt of the state (Kaur *et al* 2016). Worldwide maize production is reduced to about 40% due to competition from weeds, which form an important pest group (Oerke and Dehne 2004). Control of *Dactyloctenium aegyptium, Cynodon dactylon, Digitaria sanguinalis, Echinocloa* spp. and *Rottboellia exaltata* as grasses; *Parthenium hysterophorus, Commelina benghalensis, Amaranthus viridis, Euphorbia geniculata, Digera arvensis and Trianthema portulacastrum* as broadleaf weeds and *Cyperus rotundus* as sedges remain a problem for the farmers, especially when too high or too low soil moisture hinders the intercultural operations and scarcity of labour during critical stages of weeding (Swetha *et al* 2015). This weed flora has been traditionally controlled through pre-emergence application of herbicides (Rana *et al* 2017).

In Punjab, maize is cultivated during rainy season gets heavily infested with *Trianthema portulacastrum, Celosia argentia, Phyllanthus niruri, Amaranthus viridis*, *Eleusine aegyptiacum, Acrachne racemosa, Echinochloa colonum, Digitaria sanguinalis, Digera arvensis, Commelina benghalensis* and *Cynodon dactylon.* Sandhu *et al* (1996) reported 75 weed species in maize fields of Punjab. They found that predominant weeds associated with the crop were *Eleusine aegypticum*, *Eragrostis tenella*, *Trianthema portulacastrum, Digera arvensis* and *Cyperus rotundus*.

Manual weeding is quite effective but becoming less popular among farmers as it is time consuming, costly and moreover labour is not easily available. Whereas, in absence of manual weeding, farmers in irrigated areas mainly rely on herbicides to control weeds. Herbicide application is cost effective method for controlling weeds in maize. Use of pre-emergence herbicides gets more importance due to their effectiveness at initial stages. Many times due to various constraints at farm level, the application of pre-emergence herbicide is not possible and also continuous use of same herbicide might cause resistance in weeds. Under such situations, the post emergence herbicides are another option. Further, post-emergence herbicides applied at about 40-45 days after sowing help in avoiding the problem of weeds at later stages (Kumar and Angadi 2014). Sequential use of pre- and post-emergent herbicides at temporal variation may help in avoiding the problem of weeds throughout the maize growth stages (Sahoo *et al* 2016).

Though herbicides provide effective control of weeds and are economical but their injudicious use has lead to shift in weed flora, resistance in weeds and environment pollution. So, to reduce dependence on herbicides, non-chemical measures of weed management are also gaining importance. Among non-chemical measures, mulch is an important agronomic practice for controlling the weeds in various crops. Mulches are the left-over crop residues after the harvest of preceding crop above the soil surface. Different types of materials are used as mulches like paddy or wheat straw, grass weeds, charcoal layer and plastic films. These benefit in many ways like suppression of weeds, regulate temperature of soil, enhances soil porosity and infiltration rate of water during heavy rains and controls soil erosion, runoff and insect pest attack (Bhatt and Khera 2006, Sarkar and Singh 2007, Anikwe *et al* 2007, Glab and Kulig 2008). Mulch application may selectively reduce the weed pressure through the physical presence on soil surface (Teasdale *et al* 1991). Mulches show positive effects on moisture, heat, air regime of the soil and also restrict the evaporation and weed growth (Choudhary and Kumar 2014). The use of mulches increased the root growth and maize yield by enhancing N-uptake efficiency and reducing N losses as compared to un-mulched treatments (Aulakh *et al* 2000). The effectiveness of this technique can be further enhanced by the application of post emergence herbicides.

Weed management in any crop must aim at reducing the weed population to a level at which occurrence of weeds has no effect on farmer's economic and ecological interests. Use of herbicide as a single weed control approach may not be enough to manage the weeds below economic threshold level. Weeds in maize are mainly managed by using herbicides and manual weeding. In maize, most of the presently recommended herbicides control only few weed species. Different pre and post-emergence herbicides have been recommended in maize for controlling weeds, that are used alone or in combination. Though mulch application plays an important role in suppressing the weed flora, but its efficacy for controlling the weeds may vary at different mulch levels and their combination with either pre-emergence or post emergence herbicides, this knowledge is lacking in literature. In order to achieve an integrated weed management approach in maize, studies need to be done on straw mulch in combination with herbicides. Therefore, the present investigation was carried out with the following objectives:

1. To study the effect of straw mulch and herbicides on weed dynamics in maize.
2. To assess the effect of straw mulch and herbicides on growth and yield of maize.

CHAPTER II

REVIEW OF LITERATURE

The research work on the proposed research problem entitled "Weed management in maize (*Zea mays* L.) using straw mulch and herbicides" available in the published literature is reviewed under the following heads:

2.1 Weed spectrum associated with maize crop

2.2 Losses caused by weeds in maize crop

2.3 Effect of herbicides on weed control and maize yield

2.4 Effect of mulch on weed control and maize yield

2.5 Integrated effect of mulch and herbicides on weed control and crop yield

2.1 Weed spectrum associated with maize

Maize being a C_4 plant is one of the most important cereal crop grown under diverse soil and climatic conditions. In India, maize-wheat is a major cropping system adopted on a large scale in Indo-gangetic plains of the country. The low productivity in maize may be due to many limiting factors of which poor weed management poses severe threat to crop productivity. The predominant weed species associated in maize are *Dactyloctenium aegyptium, Eleusine indica, Cynodon dactylon, Echinochloa colona, Brachiaria reptans, Digitaria sanguinalis, Sorghum halepense, Panicum* spp., *Digitaria ciliaris, Leptochloa chinensis* and *Commelina benghalensis* as grasses, *Ageratum conyzoides, Oxalis latifolia, Celosia argentea, Cleome viscosa, Sida acuta, Portulaca oleracea, Phyllanthus niruri, Amaranthus viridis, Tridax procumbens, Ipomoea pestigridis, Parthenium hysterophorus* and *Euphorbia hirta* as broadleaf weeds and *Cyperus rotundus* as sedges. These weed species varies with location, climatic conditions, cultural practices, crop rotation, soil management, weed control measures and inherent weed seed bank in the soil. Weed plants are blessed with many growth characteristics and adaptations which enable them to exploit successfully numerous ecological niches. Certain weeds by virtue of favourable adaptations like synchronized germination, shading effects by the crop at the time of establishment, quick response to available soil moisture and nutrients, adaptation to adverse soil and climatic conditions, herbicide resistance, morphological similarity and ready contamination with crop seeds make them associated with the specific crops. Weed flora changes with respect to location viz *Cyperus rotundus* and *Trianthema portulacastrum* were dominant weed species in spring maize at Hisar (Singh *et al* 1998) whereas at Orrisa, *Cynodon dactylon*, *Digitaria sanguinalis*, *Digitaria ciliaris*, *Leptochloa chinensis*, *Dactyloctenium aegyptium*, *Eleusine indica*, *Cyperus rotundus, Cyperus iria, Celosia argentea, Commelina benghalensis, Sida acuta* and *Aschynomene indica* were found dominant in rainfed maize (Rout and Satapathy 1996).

Sharma and Thakur (1998) observed that *Commelina benghalensis, Tridax* *procumbens, Cyperus rotundus, Cynodon dactylon, Portulaca oleracea, Acalypha indica, Amaranthus viridis, Phyllanthus niruri* and *Chenopodium album* were prevalent weed species in maize under mid hill conditions of North Western Himalayan regions. *Digitaria sanguinalis, Eleusine indica, Setaria glauca, Panicum dichotomiflorum, Cynodon dactylon, Sorghum halepense, Commelina benghalensis* among grasses and *Cyperus* species among sedges and *Galinsoga parviflora, Ipomoea pestrigridis* and *Euphorbia hirta* among broadleaf weeds were dominant in maize. *Cyperus rotundus* as sedges was the most dominant weed in maize fields at Almora, Uttaranchal (Pandey *et al* 2001). However, at Pantnagar during *kharif* season *Echinochloa colona, Trianthema portulacastrum, Cyperus rotundus* and *Eleusine indica* were the dominant weeds in maize fields (Singh and Prasad 1994). During *rabi* season *Chenopodium album, Chenopodium murale, Anagallis arvensis, Melilotus indica, Euphorbia hirta, Convolvulus arvensis* as broadleaf weeds, *Cynodon dactylon* as grasses and *Cyperus rotundus* as sedges were the dominant weed flora in maize (Porwal 2000). Many grass and broadleaf weeds were observed in maize, among which *Amaranthus retroflexus* and *Chenopodium album* were the most troublesome (Zaremohazabieh and Hossein 2011). Singh and Dangewal (2013) while conducting an intensive survey of weed flora in maize fields of districts Rajouri (Jammu and Kashmir) reported 104 weed species belongs to 3 monocots and 30 dicot families. Out of 33 families of weeds, the monocot family *Poaceae* was predominant with 16 weed species which is followed by dicot families *Amaranthaceae* and *Asteraceae*, each family having 12 and 10 weeds, respectively. Shailey and Gaur (1993) studied the crops and weeds association of Pauri district of Uttrakhand and reported 180 weed species of 50 angiospermic families and out of these, *Commelinaceae* and *Poaceae* were the dominant families in maize crop.

Sandhu *et al* (1999) reported 75 weed species in maize fields of Punjab, the predominant weeds associated with the crop were *Eleusine aegyptium*, *Eragrostis tenella*, *Trianthema portulacastrum*, *Digera arvensis* and *Cyperus rotundus*. Ndam *et al* (2014) studied the weeds infesting maize crop in the South West Region of Cameroon and reported a total of 53 weed species out of which five were the problematic weeds viz., *Amaranthus spinosus, Bidens pilosa, Commelina benghalensis, Mariscus alternafolius* and *Cynodon dactylon.* They further investigated that the weeds belong to different families with *Asteraceae* as the most dominant (15%) of the weed flora of the crop and was followed by *Poaceae* (8%), *Fabaceae* (6%), *Euphorbiaceae* (6%) and *Amaranthaceae* (6%). These five families contributed 41 per cent of the weed flora of maize crop.

The different studies indicate that climatic, edaphic and biotic factors of the environment determine the distribution of weed species, their type, prevalence and intricate relationships resulting in association of weeds whose ecological requirements tally with the crop.

2.2 Losses caused by weeds in maize

Maize is an important cereal grain crop**.** Among different biotic and abiotic factors responsible for reducing the crop yields, competition posed by weeds has been a major challenge in crop production as weeds cause severe reduction in yield by competing with crop plants for limited resources like light, space applied nutrients and water also. Weeds are the undesirable plants which affect the crop production, both in quality and quantity and also the effective resource utilization by crop plants. Thus, weeds are the plants which do more harm than benefits. Weed control is a major challenge in maize production as weeds can curtail grain yield by 86% (Bijanzadeh and Hossein 2006). Globally, weed caused 10 per cent losses in agricultural production due to their competitive effect even regular control of weeds in most agricultural systems (Zimdahl 2004). Severe infestation due to wider row spacing inflicts huge losses in yield, may be up to 52 per cent in maize (Walia *et al* 2005). The extent of losses due to weeds, however, depends upon different weed species associated with crop, severity and critical period of weed infestation as determined by the density, biomass and spatial distribution of weeds in crop field, competitive ability of crop plants including the growth habit, canopy architecture and duration of crop, climatic conditions favouring the growth of weed plants and soil fertility status. Although, maize (*Zea mays* L.) is a vigorous and tall growing crop, but it is susceptible to competition from weeds with losses more than 30 per cent commonly reported. Poor weed control leads to spread of weeds throughout the growing season and causes maize yield loss. Wilson and Westra (1991) observed that delay in controlling weeds till 6 weeks after planting, there was 16 to 28 per cent reduction in maize grain yield. Worldwide maize production is hampered up to 40 per cent by competition from weeds (Oerke and Dehne 2004). Even small weeds during first week after emergence can reduce the grain yield substantially. Oerke (2005) reported that weed caused 37% loss potential which is followed by 18% through insect pests, 16% by fungal and bacterial pathogens and 2% by viruses.

Competitive weeds in dense population may reduce crop yield by more than 50 per cent by sharing available nutrients, space, soil moisture and light. Worldwide, weeds caused a significant reduction in yield with mean value of 12.8 per cent even with weed control application and 29.2 per cent under unweeded control in maize (Ngouajiro *et al* 2006). The season-long weed competition caused considerable yield losses in maize (Dalley *et al* 2006). In another study, weeds reduced maize grain yield by 35-70 per cent if not managed (Ford and Pleasant 1994) and uncontrolled weed growth brought about 83 per cent decline in average grain yield (Usman *et al* 2001). Unchecked weed growth in maize causes yield losses even up to 100% (Sharma 2005). Panwar *et al* (1992) reported that economic yield of maize was reduced by 20-40 % due to the presence of different weed species. Crop-weed competition may lead to reduction of maize yield up to 86% and of these *Amaranthus* spp.

and other annual grasses reduce yields up to 50% (Grichar and Minton 2006). Pandey *et al* (2002) reported 77.4 per cent reduction in grain yield by grasses followed by 44.2 per cent by broadleaf weeds and 38.4 per cent by sedges. Donovan *et al* (2000) observed that the relative time of crop and weed emergence is the most important factor to determine the crop weed competition. However, different weed species and density may affect the magnitude of yield losses. The weeds emerged at the time of crop emergence will cause more yield losses than those emerged at later stages.

Sharma *et al* (2000) reported the reduction in grain yield of maize up to 32.4 to 42.3 per cent which may be attributed to severe weed infestation. *Trianthema portulacastrum*, a strong competitor of maize caused substantial yield losses to the extent of 4.2 to 30.2 per cent depending upon intensity of infestation (Saeed *et al* 2010). Page and Willenborg (2013) observed that when *Echinochloa crusgalli* germinated after maize emergence then its higher weed density greatly declines the grain yield. Therefore, weed control is an important management approach for maize to ensure optimum grain yield. Yakadri *et al* (2015) reported 30-93% losses in grain yield of maize due to its wider spacing and initial slow growth. Singh *et al* (2016) conducted an experiment on maize at Ludhiana and reported that yield attributes characters and yield of maize were decreased due to enhancement in crop-weed interference duration, however the yield was enhanced with long duration of weed free period. They observed significant reduction in grain yield of maize between 30 to 60 days after sowing (DAS).

Therefore diverse weed flora causes huge losses in maize yield. If the weeds are not managed at right time then it results in huge yield penalty.

2.3 Effect of herbicides on weed control and maize yield

Salarzai (2001) evaluated various herbicides at Pakistan for controlling weeds in maize and reported that density and dry matter accumulation (DMA) of weeds and different parameters of yield were affected significantly by herbicides. The maximum grain yield (5.16 t ha^{-1}) of maize was recorded with the application of Gesaprim 80 WP as compared to 3.12 t ha^{-1} under control treatment and the increase in yield was 54.5 per cent over control. Woldetsadik and Chinawong (2005) investigated that weed population and dry matter production of weeds were effectively suppressed with pre - emergence application of atrazine / metolachlor at 3.0 kg ha^{-1} + post-emergence application of 2, 4-D at 1.0 kg ha^{-1} and resulted in increased grain yield of maize by 13.4 % over unweeded control. Patel *et al* (2006) observed that pendimethalin + atrazine both at 0.5 kg ha^{-1} as pre-emergence spray resulted in less density of monocot and dicot weeds at all time intervals and also observed highest yield of maize in comparison to all other treatments. Walia *et al* (2007) observed that integration of hand weeding with pre-emergence spray of atrazine produced significantly higher grain yield of maize and less dry matter accumulation by weeds over unweeded control. Rao *et al* (2009) conducted a field experiment in Andhra Pradesh on clay loam soil and observed that atrazine at 1.5 kg ha^{-1} as pre-emergence spray followed by one hand weeding at 30 DAS was found efficient method for weed control in maize.

Barla *et al* (2016) conducted a field experiment at Ranchi and reported that atrazine + pendimethalin both at 0.50 kg ha^{-1} as pre-emergence application was statistically similar to two hand weedings at 20 and 40 days after sowing and recorded significantly less density and DMA of weeds in comparison to weedy check at 30 and 60 days after sowing. This treatment significantly increased the plant height, number of grains per cob, 1000 grain weight as well as 65.6% higher grain yield in comparison to unweeded check (1.309 t ha^{-1}) and resulted in consequently higher net returns (₹ 53492 ha^{-1}) and benefit cost ratio (3.57) than rest of the treatments.

Kaur *et al* (2016) laid out a field experiment at Ludhiana to evaluate the efficacy of glyphosate 41% SL against complex weed flora in maize. The treatments consisted of glyphosate 41% SL at 900, 1800 and 3600 g ha^{-1} applied as directed post-emergence, pre-emergence application of atrazine 750 g ha^{-1}, post-emergence application of paraquat 24 SL 500 g ha^{-1} and 2,4-D sodium salt 1000 g ha^{-1}, weed free and unweeded control. The results revealed that non-selective herbicides paraquat at 500 g ha^{-1} and glyphosate at 900 and 1800 g ha^{-1} as post-emergence directed spray in maize showed effective control of grass and broadleaf weeds during both the years and recorded grain yield statistically similar with pre-emergence application of atrazine 750 g ha^{-1}.

Owla *et al* (2015) conducted a field experiment at Udaipur, to evaluate the effect of fertility levels, nutrient sources and weed control on productivity of quality protein maize. Application of pre-emergence atrazine 0.4 kg + alachlor 2.0 kg ha^{-1} followed by hoeing and weeding resulted in minimum weed density and dry matter of weeds but recorded maximum benefit: cost ratio.

Sahoo *et al* (2016) conducted a field experiment at Dharwad and reported that weed free check recorded higher weed control index (97.26%) than all other methods of weed control at all the growth stages in maize. However, pre-emergence application of atrazine at 1.0 kg ha^{-1} followed by post-emergence application of glyphosate at 2.5 kg ha^{-1} recorded WCI of 92.12% next to weed free check. Weed free treatment resulted in significantly higher grain yield of 84.59 q ha^{-1}, stover yield of 114.10 q ha^{-1} and harvest index of 42.57 per cent.

Field trials were conducted at Palampur by Rana *et al* (2017) to assess the impact of tembotrione on weed parameters, growth and yield of maize. The weed control treatments consisted of tembotrione 100, 125 and 150 g ha^{-1} each applied on 20 and 30 DAS in maize, tembotrione at 125 and 150 g ha^{-1} + surfactant (stefes mero 2.5 ml l^{-1}) applied on 20 DAS of maize, atrazine 1000 g ha^{-1} (pre) fb atrazine 750 g ha^{-1} (post), atrazine 1000 + pendimethalin 1000 g ha^{-1} (pre), manual weeding thrice (20, 40 and 60 DAS) and unweeded check.

Tembotrione at 125 and 150 g ha^{-1} with surfactant (20 DAS) and at 150 g ha^{-1} without surfactant (30 DAS) effectively reduced the dry weight of *Echinochloa colona, Commelina benghalensis, Polygonum alatum, Ageratum conyzoides* and the combined weight of all weeds. Tembotrione 125 and 150 g ha^{-1} + surfactant (20 DAS) produced significantly higher grain yield of maize followed by tembotrione 150 g ha^{-1} applied on 30 DAS, tembotrione 125 g ha^{-1} applied on 30 DAS and tembotrione 150 g ha^{-1} applied on 20 DAS. Grain yield of maize was negatively correlated with dry weight of *Echinochloa, Commelina, Polygonum, Ageratum* and the combination of all weeds. With every 1g m^{-2} increase in DMA of weeds, the maize grain yield was reduced by 33.7 kg ha^{-1}. Tembotrione 150 g ha^{-1} + surfactant and tembotrione 125 g ha^{-1} + surfactant applied on 20 DAS and tembotrione 150 g ha^{-1} applied on 30 DAS gave highest weed control efficiency, crop resistance index and efficiency index, but lowest weed index over other treatments. The results indicated that the grain yield of maize was reduced by 63.5% due to continuous growth of weeds.

Swetha *et al* (2015) observed that application of tembotrione at 105 + atrazine at 250 g ha^{-1} + stefes mero as post-emergence, atrazine at 1.0 kg ha^{-1} followed by hand weeding at 30 days after sowing and intercropping of maize with cowpea and pendimethalin at 1.0 kg ha^{-1} as pre-emergence reduced the weed density and weed biomass significantly as compared to unweeded control at 20 DAS.

Gul *et al* (2016) conduced an experiment under temperate Kashmir conditions and the results revealed that application of atrazine as pre-emergence + one hand weeding at 20 DAS was statistically at par with treatment of atrazine as pre-emergence + isoproturon as post-emergence application treatment and both showed significant increase in all yield attributing parameters in comparison to no weeding and two hand-weeding at 20 and 50 DAS. Pre-emergence application of atrazine + hand weeding at 20 DAS resulted in maximum grain and stover yield of maize in comparison to hand weeding on 20 and 50 days after sowing and no weeding.

Mavunganidze *et al* (2014) carried out the experiment at Zimbabwe to study influence of tillage methods and weeding treatments on density of weeds, plant height and maize grain yield. The results showed that weed competition was reduced by tank mix application of atrazine at 1.46 kg ha^{-1} + alachlor at 0.96 kg ha^{-1} treatment as pre- emergence spray. This treatment gave maximum maize grain yield and was on par with alone application of atrazine.

An investigation was carried out by Chopra and Angiras (2008) at Palampur to find out the effect of three tillage methods viz. zero tillage, conventional tillage and raised seed-bed and four weed control treatments (unweeded check, acetachlor 0.75 kg ha^{-1}, acetachlor 1.25 kg ha^{-1}and atrazine 1.5 kg ha^{-1}) on nutrient uptake and productivity of maize. Raised seed-bed method recorded significantly lower density and DMA of weeds. Atrazine 1.5 kg ha^{-1}, being statistically similar with acetachlor 1.25 kg ha^{-1}, lowered the density and DMA of weeds. In comparison to weedy, atrazine at 1.5 kg ha^{-1} and acetachlor at 1.25 kg ha^{-1}, being statistically similar, significantly enhanced the uptake of N, P and K and the grain yield of maize.

Kumar *et al* (2012) conducted a field experiment at Palampur and tested different treatments combinations consisting tank-mix combinations of pre-emergence application of atrazine and pendimethalin as followed by of 2,4-D and metsulfuron methyl as post emergence spray along with hand weeding at 20 and 40 days after sowing and uuweeded check in maize. *Commelina benghalensis, Panicum dichotomiflorum*, *Digitaria sanguinalis, Echinochloa colona, Cyperus iria, Ageratum conyzoides* and *Polygonum alatum* were the predominant weed species. Application of pendimethalin at 1.50 kg ha^{-1}, atrazine followed by atrazine 0.75 kg ha^{-1}, atrazine 0.75/1.0 + pendimethalin 0.75/0.50 followed by metsulfuron methyl 4 g ha^{-1} reduced the density of *Echinochloa colona*. Atrazine followed by atrazine effectively controlled the density of *Panicum dichotomiflorum* till 60 days after sowing. Pendimethalin followed by atrazine, atrazine 1.0 + pendimethalin 0.50 followed by 2, 4-D 0.75 kg ha^{-1} and hand weeding at 20 and 40 days after sowing significantly lowered the population of *Commelina benghalensis* till 60 days after sowing. Pendimethalin/atrazine fb atrazine and atrazine + pendimethalin followed by 2, 4-D/ metsulfuron-methyl reduced density of *Ageratum conyzoides* till 60 days after sowing. Pendimethalin/atrazine followed by atrazine, atrazine + pendimethalin followed by metsulfuron-methyl/2, 4-D and pendimethalin significantly decreased total DMA of weeds. Significantly highest grain yield and net returns was obtained with application of Atrazine 1.0 + pendimethalin 0.50 kg ha^{-1} and atrazine + pendimethalin both at 0.75 kg ha^{-1} followed by 2, 4-D treatments. They observed that grain yield of maize was reduced by 50.3 per cent due to presence of weeds.

Yakadri *et al* (2015) carried out a field experiment at Andhra Pradesh and revealed that importance value index of 37.64, 32.29, 16.33 and 13.37 was obtained with *Echinochloa colona*, *Panicum repens*, *Trianthema portulacastrum* and *Digera arvensis*, respectively. Among weed management treatments, hand weeding at 15-21 days after sowing and 30-42 days after sowing and integration of pre-emergence application of atrazine 1.5 kg ha^{-1}, pendimethalin at 1.50 kg ha^{-1}, atrazine + alachlor at 0.75 + 1.25 kg ha^{-1}, or alachlor at 1.5 kg ha^{-1} fb hand weeding at 30 days after sowing were proved more effective. In case of sequential treatments, pre-emergence application of atrazine at 1.25 kg ha^{-1} or pendimethalin at 1.5 kg ha^{-1} fb paraquat at 0.6 kg ha^{-1} at 3 weeks after sowing or pre-emergence application of atrazine at 1.0 kg ha^{-1} followed by topramazone at 0.030 kg ha^{-1} at 30 days after sowing gave higher gross returns, net returns and benefit cost ratio, thus proved more economical.

Arvadiya *et al* (2012) conducted a research trail at Navsari to assesed the effect of 3 plant populations viz. 1,11,111, 83,333 and 74,074 plants ha^{-1} and 8 weed control strategies viz. weedy check, weed free check, atrazine 1.0 kg ha^{-1} as pre-emergence, atrazine 1.0 kg ha^{-1} as pre-emergence + hand weeding at 40 days after sowing, pendimethalin 1.0 kg ha^{-1} as pre-emergence, pendimethalin 1.0 kg ha^{-1} as pre-emergence + hand weeding at 40 DAS, atrazine 0.50 kg ha^{-1} + pendimethalin 0.25 kg ha^{-1} as pre-emergence and hand weeding at 20 days after sowing + inter culture at 40 days after sowing on weed dynamics and productivity of sweet corn. The predominant weed flora were *Echinochloa crusgalli* and *Cynodon dactylon* as monocots; *Cyperus rotundus* as sedges and *Amaranthus viridis, Alternethara sessili, Portulaca oleracea, Digera arvensis and Trianthema* sp. as dicots. Density and DMA of weeds was significantly lowest with a plant population of 1,11,111 plants ha^{-1}. Green cob, green fodder yield, net returns and benefit cost ratio was significantly higher with plant population of 1,11,111 plants ha^{-1} which was statistically similar with plant population of 83,333 plants ha^{-1}. The DMA of weeds (83.47 kg ha^{-1}) and weed control efficiency at harvest (90.58 %) were lowest in weed free treatment. Atrazine at 1.0 kg ha^{-1} as pre-emergence + hand weeding at 40 DAS gave maximum net returns (₹ 88,873 ha^{-1}) and benefit cost ratio (6.72) in comparison to other herbicides.

2.4 Effect of mulch on weed control and maize yield

Uwah and Iwo (2011) conducted an experiment on maize in Nigeria and observed less plant height, reduction in number of leaves per plant and highest weed intensity in the unmulched treatment as compared to mulch treatments. Weed infestation in the unmulched plots was increased by 6 and 11 times as compared to mulch applied plots at 6 and 8 t ha^{-1}, respectively. Maximum plant height and number of leaves per plant were observed in those plots where mulch at 8 t ha^{-1} whereas grain yield, dry stover yield and grains weight per cob was higher at 6 t ha^{-1}. More than double grain yield of maize was observed under mulched treatments in comparison with unmulched treatment. Zamir *et al* (2013) **c**onducted a field experiment to study the effect of organic mulches and tillage practices on growth, yield and quality of maize. The combined effect of wheat straw mulch and zero tillage produced maximum thousand grain weight and grain yield followed by saw dust mulch and conventional tillage.

Choudhary and Kumar (2014) carried out an experiment at Basar and reported that mulch application resulted in 18 to 35 per cent higher productivity of sequential crops in comparison to no mulch treatment. Highest weed density, DMA and persistency of weed were recorded under maize-fallow. Maximum weed-smothering efficiency of 59.4 per cent was recorded with maize-groundnut cropping system. Mulch applied plots recorded least all weed parameters with weed-smothering efficiency of 65 per cent. Also, no mulched plots showed less amount of soil moisture as compared to mulched applied plots.

A field experiment was carried out by Dutta *et al* (2016) during the winter season on sandy-clay loam soil at West Bengal to assess the influence of different weed-control methods on weed parameters, soil-microbial populations and productivity of baby corn. Significantly lowest weed DMA and weed index, whereas highest weed-control efficiency and uptake of nutrients was recorded in weed free treatment and hand weedings at 20 and 40 DAS in comparison to other weed-control treatments. These treatments were followed by mulch 10 t ha^{-1} and ehhanced yield by 68.98 per cent over unweeded check. Straw-mulch treatment also showed the maximum favourable effect on growth of microbial populations in soil.

Mahajan *et al* (2007) conducted field experiments at Ludhiana and reported that plastic mulch increased yield of baby corn by 18.9 and 77.5 per cent over paddy straw and no mulch treatment, respectively. They further reported that there was 28.6 per cent increase in yield with application of plastic mulch at irrigation level of 0.8 ETc in comparison to no mulch treatment.

A field experiment was conducted by Bahar (2013) during *kharif* season at the Kashmir to assess the relative performance of resource conservation technologies in maize based cropping systems. Four tillage methods (conventional tillage, minimum tillage, zero tillage and bed planting) as main plot treatments and two mulch treatments (no mulch and straw mulch) as sub plot treatments. The results indicated that grain yield of maize by about 14.4 percent was enhanced with the application of mulch. Significantly highest net returns and benefit cost ratio was obtained with straw mulch in comparison to no mulch.

An experiment was carried out by Ali *et al* (2011) at the new developmental farm, Khyber Pakhtunkhwa Agricultural University Peshawar, Pakistan to assess the influence of different weed management strategies on weeds growth and grain yield in maize. The experiment comprising seven different weed management treatments including sorghum mulch, wheat straw, news papers, black plastic, a hand weeding, a herbicide (Primextra gold at 1l ha^{-1}) and a weedy check. All the treatments affected the weed parameters like density and DMA of weeds and yield attributes of maize. Highest weed density (82 plants m^{-2}) and DMA of weeds (1097 kg ha^{-1}) were recorded in the unweeded check, which were statistically similar with wheat straw (63 plants m^{-2} and 951 kg ha^{-1}, respectively) and news paper mulched treatments (73 plants m^{-2} and 920 kg ha^{-1}, respectively).

Sharma *et al* (2010) conducted a research trail at Dehradun and reported that productivity of maize was 5.6 to 8.8 per cent higher with application of legume mulch at 30 DAS in comparison to no mulch tratment. Grain yield of succeeding wheat crop was enhanced by 13.3 to 14.0 per cent due to application of legume mulch in previous maize following with increased soil moisture and nutrient conservation. Legume mulch was superior in comparison to mulch with weed biomass in maize and wheat.

Bua *et al* (2013) evaluated the effect of two mulch methods on the crop growth, yield and water-use efficiency of maize at the Changwu experimental station. The experiment was designed to study with three mulch treatments viz. non-mulch, gravel-mulched and plastic film mulched. Compared to non-mulch, the grain yield was increased by 17.0 and 28.3 per cent in 2010, and 70.2 and 87.5 per cent in 2011 with gravel and plastic film mulch treatments, respectively.

Murungu *et al* (2011) reported that low soil fertility and weeds reduce maize yields on most smallholder irrigation schemes in South Africa. They found that mulching with oat and grazing vetch significantly decreased weed DMA in comparison to mulching with lupin mulch and no mulch treatment.

Sarwar *et al* (2013) from Faisalabad reported that mulch plays an important role mainly in soil moisture conservation and in suppressing weeds growth. In order to determine the effect of various mulch techniques under zero tillage system, a field experiment on wheat was conducted with six treatments, viz. no mulch (control), animal manure at 4 t ha^{-1}, rice straw mulch at 4 t ha^{-1}, maize straw mulch at 4 t ha^{-1}, wheat straw mulch at 4 t ha^{-1} and burned rice straw after harvesting. The results showed that higher weeds biomass reduction (41 g) was attained in rice straw mulch at 4 t ha^{-1} treated plots parallel to other mulch treatments. Maximum grain yield (5.16 t ha^{-1}) and yield attributing characters of wheat like number of spike bearing tillers (385.6 m^{-2}), spikelets per spike (18.6), grains $spike^{-1}$ (53.2) and 1000-grain weight (52.2 g) were highest in rice straw mulch at 4 t ha^{-1} treated plots.

Shah *et al* (2014) conducted an experiment at Islamabad to assess the efficacy of different mulches for reducing weeds in maize. The results showed that minimum weed density was observed under black plastic mulch in comparison to unweeded control, except hand weeding. Similarly, maximum grain yield was obtained under black plastic mulch, while minimum grain yield was obtained under unweeded control. Net returns recorded from maize under black plastic mulch were significantly higher in comparison to unweeded control. The grain yield of maize was increased by 21.1 and 16.5 per cent with plastic mulch and weeds as mulch, respectively over hand weeding. They recommended black plastic followed by weeds as mulch for controlling weeds and getting maximum yield as well as net economic returns.

2.5 Integrated effect of mulch and herbicides on weed control and crop yield

Mulch application helps in suppressing weed seed germination and dry matter of weeds. The integration of mulch and herbicide could help in providing effective control of weeds. Chauhan and Abugho (2013) estimated the integrated effect of herbicide and different rice straw mulch levels on weed dynamics and yield parameters in dry seeded rice. An inverse relationship was observed between weed biomass and increase in mulch levels in the herbicide non-treated plots whereas DMA of weeds was found to be similar at different mulch rates in herbicide treated plots. Grain yield was higher in the herbicide-treated plots with rice straw mulching at 4.0 t ha^{-1} as compared to only rice straw at 2.0 t ha^{-1} and no mulch treatment, while in the non-treated plots the grain yield was similar at different mulch rates. The findings indicated that combined use of mulch and herbicides can help in better management of weeds and maximizing the grain yield.

Kumar and Angadi (2014) conducted a field experiment during *kharif* season in Karnataka and found that tillage, mulch and weed management practices significantly influenced the growth and yield of maize. Atrazine application fb 2, 4-D resulted in higher grain yield in comparison to all other treatments. The integration of conventional tillage, mulch and atrazine 1.25 kg ha^{-1} fb 2,4-D 2.0 kg ha^{-1} and integration of minimum tillage, mulch and atrazine fb 2,4-D increased the growth, yield attributes and economic returns in maize with comparison to all other treatments.

From the above review it can be concluded that due to diverse weed flora, weeds become a major constraint in maize. The yield losses in maize due to weeds vary from location to location owing differences in management practices, climate and other factors. The success of maize crop depends upon the weed control by using herbicides. However, herbicides should not be considered as replacement for other weed control measures but can be used in combination with these measures. The use of mulch has shown promising results for reducing weed pressure in maize. The combination of chemical and non- chemical approaches i.e. mulch will help in better control of weeds than use of any single approach in maize.

CHAPTER III

MATERIALS AND METHODS

The field experiment entitled, **"Weed management in maize (*Zea mays* L.) using straw mulch and herbicides"** was carried out at Students' Research Farm, Department of Agronomy, PAU, Ludhiana and Research Farm, Regional Research Station (PAU) Gurdaspur during *kharif* 2017. The detail of the materials used and the methods followed are presented in this chapter.

3.1 LOCATION AND CLIMATE

Ludhiana (30^{o}54′N latitude, 75^{o}48′E longitude) is situated at height of 247 metres above mean sea level, characterized by sub-tropical and semi-arid climate with dry and hot summer from April to June, humid and hot conditions from July to September, cold winters from November to January. February and March months have mild temperature. Highest temperature often goes to as high as 45-47^{0}C in the months of May-June, while lowest temperature touches to freezing point accompanied by frosty spells in winter months of December and January. Average annual rainfall of Ludhiana ranges from 500 to 750 mm, most of which is received from July to September i.e. monsoon period, the grand growth period of maize crop. Some rainfall is also expected during winter months.

Gurdaspur: It is situated at 32° 03' N latitude, 75° 27' E longitude and height of 265 metres above the mean sea level and is placed in the sub-mountainous region of Punjab. In summer season the temperature reaches up to 44^{0}C or even sometimes crosses it. June is found as hottest month and January is the coldest one. The normal annual rainfall of this region is about 1325 mm, 80 percent of which is usually received during the south western monsoon season and remaining during winter season.

3.1.1 Weather during crop season

Ludhiana: The meteorological data during crop season (June 2017- September 2017) are given in fig 3.1. The data indicated that higher temperature was observed during the initial growth stages and lower temperature during the maturity period. The data further revealed that maximum temperature ranged from 32.0 to 35.4^{0}C, minimum temperature ranged from 23.1 to 28.5^{0}C and mean relative humidity ranged from 64.0 to 79.0 % during the life span of crop. Total evaporation of 509.5 mm, sunshine hours of 106.1 and well distributed rainfall of 364.8 mm was recorded during crop season.

Gurdaspur: The meteorological data during crop season (June 2017- September 2017) are given in fig 3.2. The data indicated that higher temperature was observed during the initial growth stages and lower temperature during the maturity period. The data further revealed that maximum temperature ranged from 31.0 to 38.3^{0}C, minimum temperature ranged from 23.0 to 26.2^{0}C and mean relative humidity ranged from 42.5 to 83.0 % during the life span of

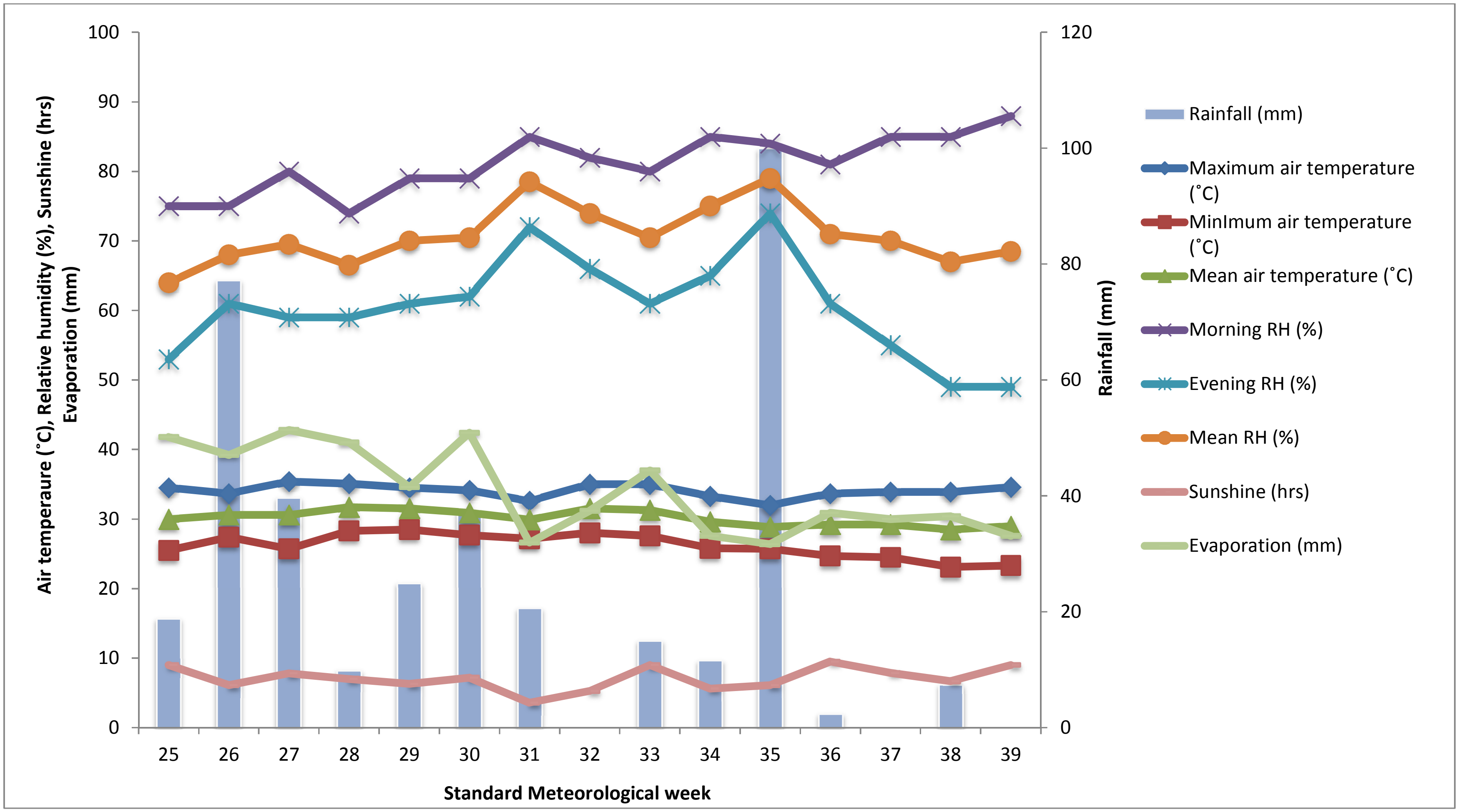


Fig. 3.1 Graphical presentation of weekly meteorological data during crop season at Ludhiana (*Kharif* 2017)

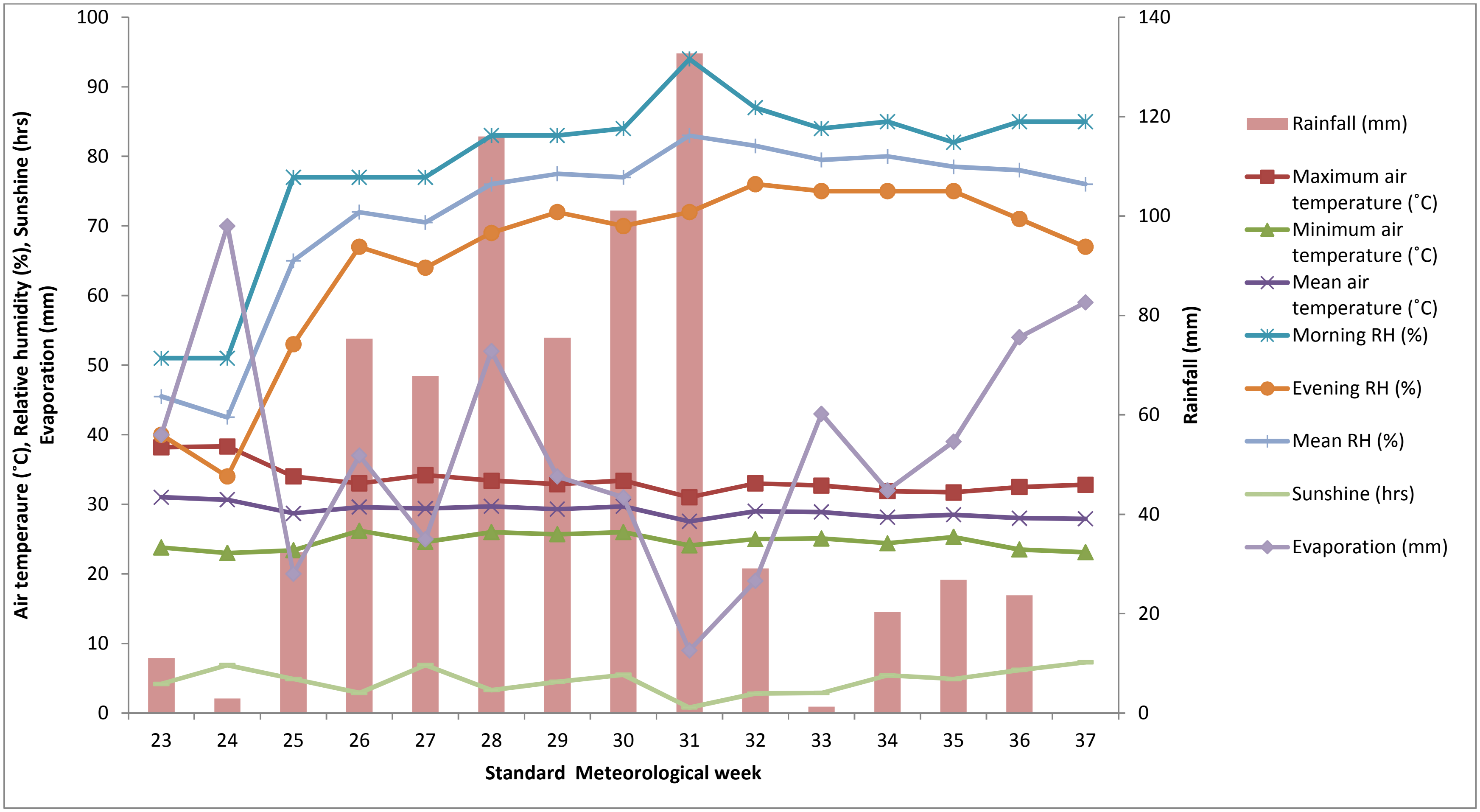


Fig. 3.2 Graphical presentation of weekly meteorological data during crop season at Gurdaspur (*Kharif* 2017)

crop. Total evaporation of 59.4 cm and sunshine hours of 69.4 were recorded during crop season but the total rainfall received during crop season was 716 mm which was well distributed.

3.2 CROPPING HISTORY OF THE FIELD

Experimental fields were under following cropping systems (Table 3.1) for the last three years.

Table 3.1 Cropping history of experimental field at Ludhiana and Gurdaspur

Year	Ludhiana		Gurdaspur	
	Kharif	***Rabi***	***Kharif***	***Rabi***
2013 – 2014	Maize	Wheat	Medicinal crops	Medicinal crops
2014 – 2015	Pigeonpea	Wheat	Medicinal crops	Medicinal crops
2015 – 2016	Pigeonpea	Wheat	Mash	Wheat
2016 – 2017	Experimental maize crop	-	Experimental maize crop	-

3.3 SOIL SAMPLING AND ANALYSIS

To assess the physico-chemical properties of the experimental field, the composite soil samples from depth of 0–15 cm soil layer were taken from randomly selected sites of the experimental field before sowing of the crop at both locations. The samples were dried in shade, ground and sieved through 2 mm sieve and analyzed. The composite samples were subjected to mechanical and chemical analysis. The details of the values obtained with respect to various properties are as follows:

3.3.1. Physico-mechanical analysis

The data with respect to physical analysis of soil are presented in table 3.2. The soil was categorized as loamy sand in texture at Ludhiana whereas at Gurdaspur it was sandy loam.

Table 3.2 Physico-mechanical properties of the experimental field

Soil depth (0-15cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class
Ludhiana	81.50	10.80	7.70	Loamy sand
Gurdaspur	61.11	12.98	25.91	Sandy loam
Method used:	International Pipette Method (Piper 1966)			

3.3.2. Chemical analysis

The chemical properties of the soil determined before the sowing of crop revealed that soil of both the experimental fields was normal with respect to electrical conductivity (EC) and pH, low in OC, available N and medium in available P and K.

Table 3.3 Chemical analysis of soil before sowing of the experimental field

Soil property	Soil depth (0-15 cm)				Method employed
	Ludhiana	Rating	Gurdaspur	Rating	
pH	7.5	Normal	7.4	Normal	Beckman's glass electrode pH meter (Jackson, 1967)
EC (dS m^{-1})	0.27	Normal	0.23	Normal	Solubridge conductivity meter (Jackson, 1967)
OC (%)	0.37	Low	0.35	Low	Walkley and Black's rapid titration method (Jackson, 1967)
Available N (kg ha^{-1})	138.1	Low	136.6	Low	Alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	17.2	Medium	18.9	Medium	0.5 M Sodium bicarbonate extractable method (Olsen *et al* 1954)
Available K (kg ha^{-1})	179.1	Medium	195.3	Medium	1N Ammonium acetate extractable method (Merwin and Peech 1950)

3.4 EXPERIMENTAL DETAILS

3.4.1 Title of the field experiment: Weed management in maize (*Zea mays* L.) using straw mulch and herbicides

3.4.2. Location of work: Student's Research Farm, Department of Agronomy, PAU, Ludhiana and Research Farm, Regional Research Station, Gurdaspur during *kharif* 2017.

3.4.3 Treatments:

Ist factor: Straw mulch: 3

1. No mulch
2. Paddy straw mulch at 6.25 t ha^{-1} (PSM 6.25 t ha^{-1})
3. Paddy straw mulch at 9.0 t ha^{-1} (PSM 9.0 t ha^{-1})

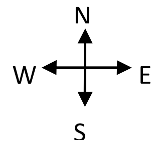
IInd factor: Weed control: 6

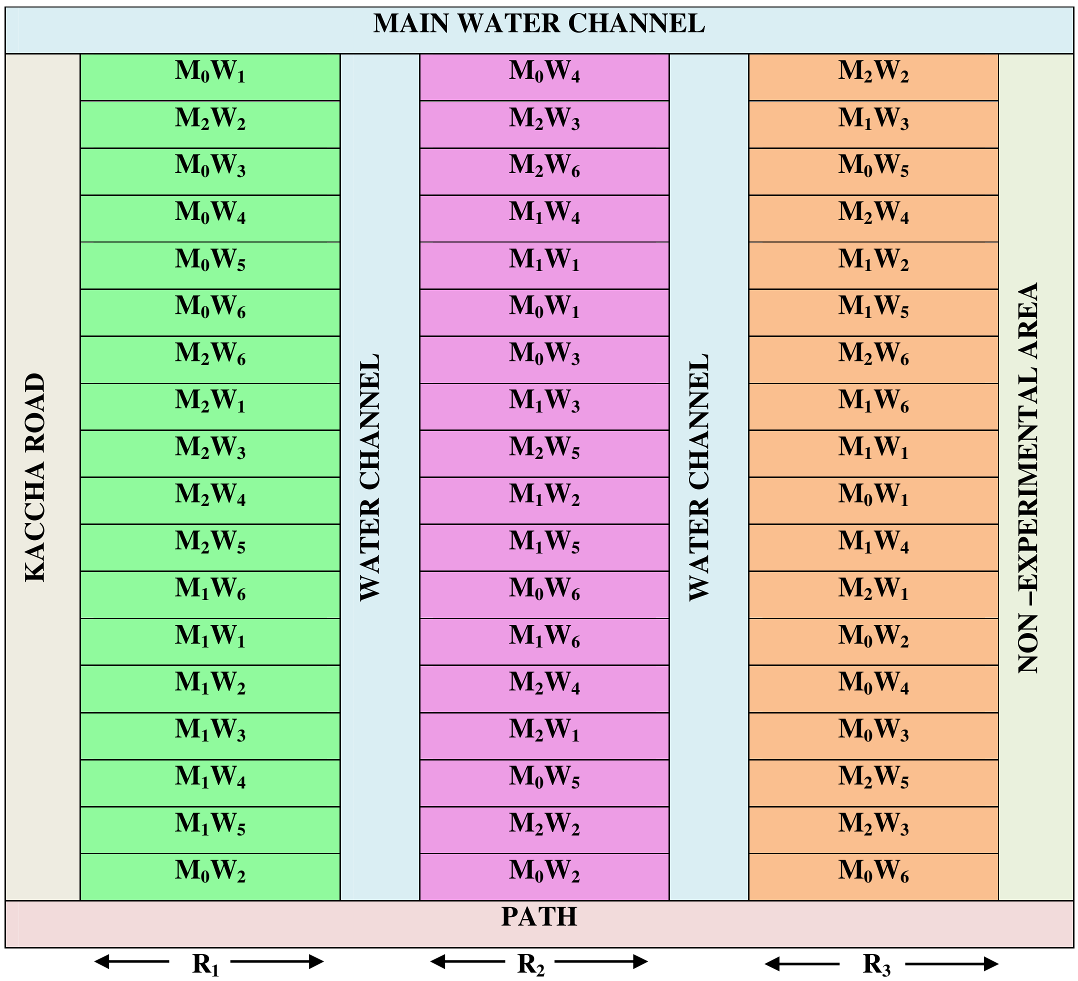
1. Atrazine at 1.0 kg ha^{-1} (recommended) pre-emergence
2. Atrazine at 0.8 kg ha^{-1} (80% of recommended) pre-emergence
3. Tembotrione at 0.110 kg ha^{-1} (recommended) at 20 DAS
4. Tembotrione at 0.088 kg ha^{-1} (80% of recommended) at 20 DAS
5. Weed free
6. Unweeded check

3.4.4 Methodology

The experiment was conducted in a Factorial Randomized Block Design (RBD) with three replications. There were three mulch treatments as first factor and six weed control treatments were taken as second factor. Net plot size was 6.0 m × 3.6 m. The recommended hybrid of *kharif* maize (PMH 1) was sown by dibbling the seed at recommended spacing. The straw mulch and weed control treatments were applied as per treatments. All other agronomic

Fig. 3.3 Layout plan of the experiment at both locations





I[st] **factor**: Straw mulch: 3

M_0 –No mulch

M_1–Paddy straw mulch at 6.25 t ha^{-1}

M_2–Paddy straw mulch at 9.0 t ha^{-1}

II[nd] **factor:** Weed control: 6

W_1– Atrazine at 1.0 kg ha^{-1}

W_2 – Atrazine at 0.8 kg ha^{-1}

W_3–Tembotrione at 0.110 kg ha^{-1}

W_4–Tembotrione at 0.088 kg ha^{-1}

W_5– Weed free

W_6– Unweeded check

practices such as fertilizers, irrigations and plant protection measures were followed as per PAU recommendations.

3.5. HERBICIDES UESD

3.5.1 Common name : Atrazine

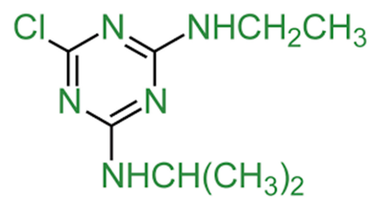
Chemical name : 6-Chloro-N-ethyl-N1-(1-methylethyl)-1,3,5-triazine-2,4-diamine

Group : Triazines

Method of application : Pre- emergence

Mode of action : Inhibition of photosynthesis at photosystem II

Structural formula:



Atrazine

3.5.2 Common name : Tembotrione

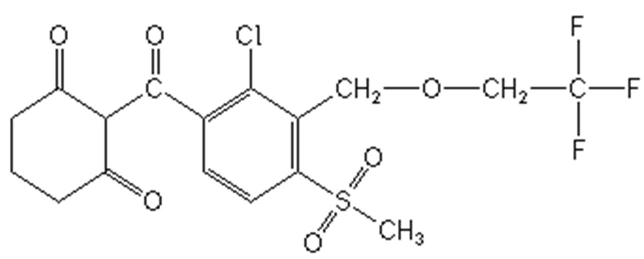
Chemical name : 2-{2-chloro-4-mesyl 3[(2,2,2trifluoroethoxy) methyl]benzoyl} cyclohexane-1,3-dione

Group : Triketone

Method of application : Post-emergence

Mode of action : Inhibition of 4-hydroxyphenylpyruvate dioxygenase (HPPD) which leads to chlorophyll destruction by photooxidation

Structural formula:



Tembotrione

3.6 CULTURAL OPERATIONS

3.6.1 Field preparation

The primary tillage operation was carried with tractor drawn disc harrow before applying pre-sowing irrigation. Pre-sowing irrigation was applied to ensure adequate moisture in soil at the time of sowing. When the field attained optimum moisture condition, fine seedbed was prepared by giving two cultivations with tractor drawn cultivators each followed by planking.

3.6.2 Method of sowing

Maize hybrid (PMH 1) was sown on June 22, 2017 at Ludhiana whereas at Gurdaspur on June 6, 2017 on a well prepared seedbed. The sowing was done by dibbling method using two seeds per hill. The flat sowing was done at spacing of 60 cm × 20 cm.

3.6.3 Seed treatment

The seed was treated with Bavistan 50WP (carbendazim) at 3 g per kg seed before sowing for protection against attack of various fungal diseases.

3.6.4 Straw mulching

Paddy straw mulch was applied in between the lines as per treatment, immediately after the emergence of maize seedlings as per the treatments.

3.6.5 Gap filling

After emergence, the gaps were filled to maintain the required plant population in each plot after 10 days of sowing.

3.6.6 Thinning

Thinning in all the treatments was done at 15 days after sowing the crop by retaining one plant per hill.

3.6.7 Fertilizer application

The whole quantity of recommended dose of P, K and zinc sulphate was applied at the time of sowing. Nitrogen was applied in the form of urea in three splits: one third nitrogen was applied at sowing, other one third at knee high stage near the plant base and remaining one third nitrogen at pre-tasselling stage. N, K and zinc sulphate fertilizers was broadcasted before planking and P fertilizer was drilled below the seed before sowing with hand seed drill.

3.6.8 Weed control

For controlling the weeds, herbicides Atrataf 50 WP (atrazine) and Laudis 420 SC (tembotrione) with activator at 1000 ml ha^{-1} were applied as pre-emergence (within 2 days of showing) and post-emergence (at 20 DAS) herbicide, respectively with knap sack sprayer as per treatments.

3.6.9 Irrigation

First irrigation was applied after three weeks of sowing and the others irrigations were applied as per the requirement of the crop depending on the rainfall. Total three irrigations were applied to the crop at Ludhiana and two irrigations at Gurdaspur during the growing season.

3.6.10 Plant protection measures

The crop was sprayed at 21 and 35 days after sowing with Decis 2.8 EC (deltamethrin) at 200 ml ha^{-1} in 150 litres of water against the attack of maize borer.

3.6.11 Harvesting

The crop was harvested manually on September 29, 2017 at Ludhiana whereas at Gurdaspur on September 15, 2017 when the stalks and leaves were slightly green but the cobs husk cover has dried, turned brown and the grains became hard. The stalks were tied along with the cobs in bundles and labeled them plot-wise before stacking in upward position. The sun-dried weight of bundles was recorded before the removal of cobs.

3.6.12 Threshing

After fifteen days of harvesting, the cobs were removed from plants manually and were allowed to dry for another seven days and thereafter the threshing was done using maize thresher.

1.7 OBSERVATIONS ON WEEDS

1.7.1 Periodic weed count

The species-wise weed count was recorded by randomly placing the quadrate (0.5 m × 0.5 m) at 20, 40 DAS and at harvest. The weed density was reported as number m^{-2}.

3.7.2 Dry matter accumulation by weeds

For dry matter accumulation, the weed samples from two randomly selected spots in the quadrate (0.5 m × 0.5 m) were cut at the ground level and then dried in hot air oven at 60±2ºC till constant weight at 20, 40 days after sowing and at harvest. The dry matter of weeds was expressed in g m^{-2}.

3.7.3 Weed index

Weed index is indirectly related to reduction in yield due to weed population and weed dry matter accumulation. Higher weed index means greater loss due to weeds.

$$\text{WI} = \frac{\text{Yield from weed free} - \text{Yield of particular treatment}}{\text{Yield from weed free}} \times 100$$

3.7.4 Weed control efficiency (WCE)

It is calculated by following formula and expressed as percentage

$$\text{WCE} = \frac{\text{DMC} - \text{DMT}}{\text{DMC}} \times 100$$

Whereas,

DMC- Dry matter of weeds in control (unweeded check) plot

DMT- Dry matter of weeds in a treatment

3.8 OBSERVATIONS ON MAIZE CROP

Growth parameters

3.8.1 Days taken to emergence

Plant emergence was noted daily after sowing of maize from one metre row length of two rows in each plot and the number of days taken for complete emergence of the seedlings was recorded.

3.8.2 Plant stand at 30 days after sowing and at harvest

Total number of plants was recorded in each plot at 30 days after sowing (DAS) and at the time of harvesting the crop and expressed as number of plants per square metre.

3.8.3 Plant height

Periodically at 30, 60 and 90 DAS and at harvest, plant height of five randomly selected plants was measured from ground level to the base of the whorl before tasselling and after that from ground level to the top of tassel. The mean plant height of these five tagged plants was computed and expressed in cm.

3.8.4 Number of leaves per plant

The plants selected for recording plant height were taken for recording number of leaves per plant and are counted at 30, 60, 90 DAS and at harvest. The average values were worked out to estimate the number of leaves per plant.

3.8.5 Dry matter accumulation

The dry matter accumulation by crop was recorded by destructive method. Two plants were selected at random in each plot for recording dry matter accumulation. The above ground portion of the plant was cut every time at 30, 60 and 90 DAS and at harvest. First the samples were sun dried and then dried in the oven at $60^{o}\pm2^{o}C$ till constant weight was obtained for recording dry matter accumulation. It was expressed in g $plant^{-1}$.

3.8.6 Leaf area

Sun Scan Canopy Analyzer instrument was used for recording leaf area index periodically at 30, 60 and 90 DAS. It was recorded from three places and mean value was calculated.

3.8.7 Chlorophyll content of leaves

Reading of chlorophyll content index was taken periodically at 30, 60 and 90 DAS with SPAD meter. Top third fully opened leaf was selected for observation. Ten readings were taken from each plot with care so that mid-rib of laef should not come under the eye of instrument and the average value was worked out.

3.8.8 Photosynthetically active radiation (PAR) interception

Line Quantum Sensor (Model MQ-200) instrument was used to measure PAR interception (wavelength range 400-700 nm) on clear sunny day at 30, 60 and 90 DAS and at harvest. Observations were taken at 2.00-3.00 pm from three places in each plot and per cent interception was calculated as under:

$$\text{PAR interception (\%)} = \frac{\text{PAR (I)} - \text{PAR (T)} - \text{PAR (R)}}{\text{PAR (I)}} \times 100$$

Where,

PAR (I) = Total PAR incoming above the canopy, Wm^{-2}

PAR (T) = PAR transmitted to ground, Wm^{-2}

PAR (R) = PAR reflected from the canopy, Wm^{-2}

Crop phenology

3.8.9 Days taken to 50 per cent emergence

This stage was recorded from sowing to the date when fifty per cent plants were emerged in each plot.

3.8.10 Days taken to 50 per cent tasselling

The numbers of days taken to tasselling were recorded from sowing to the date when tasselling was observed on fifty per cent plants in each plot.

3.8.11 Days taken to 50 per cent silking

This stage was recorded from sowing to the date when silk emergence was noticed on fifty per cent of the plants in each plot.

3.8.12 Days taken to physiological maturity

From sowing date number of days were calculated, when fifty per cent plants showed drying of cobs husk in each plot.

3.9 YIELD PARAMETERS

3.9.1 Cobs per plant

Total number of cobs per plot was counted and divided by total number of plants per plot to calculate number of cobs per plant.

3.9.2 Cob length

Cob length was measured with scale of five representative cobs from each plot and their mean values were worked out.

3.9.3 Cob girth

The cob girth of five randomly selected cobs from each plot was measured with the help of a vernier caliper from the base, centre and the top of the cob and its mean was multiplied with the value of π (3.14) and the average cob girth was calculated in centimeters.

3.9.4 Number of rows per cob

The number of rows from the five randomly selected cobs was counted from each plot and the mean values were taken as number of rows per cob.

3.9.5 Number of grains per cob

The number of grains from the five randomly selected cobs was counted from each plot and the mean values were taken as number of grains per cob.

3.9.6 1000 grain weight

All the cobs from each net plot were thrashed and one thousand grains were counted from the produce of each plot and then weighed in grams for presentation.

3.9.7 Grain yield

Maize plants were harvested from each net plot area and kept in the field for sun drying for fifteen days and shelled with maize thresher and grain yield was recorded. Grain yield was adjusted to fifteen per cent moisture content and reported as q ha^{-1}.

3.9.8 Stover yield

All the cobs were picked from each net harvested plot and the remaining plant material including husk was sun dried, weighed and expressed as q ha^{-1}.

3.9.9 Shelling percentage

Shelling percentage was calculated by dividing the grain yield (q ha^{-1}) with total weight of cobs (q ha^{-1}) and expressed as percentage.

$$\text{Shelling percentage} = \frac{\text{Grain yield}}{\text{Whole cob weight}} \times 100$$

3.9.10 Harvest index

It was calculated as the ratio of grain yield (q ha^{-1}) to total biological yield (q ha^{-1}) and expressed as percentage.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Total biological yield}} \times 100$$

3.10 QUALITY ANALYSIS/LAB STUDIES

3.10.1 Protein content in grains

Protein content in maize grains was calculated by using nitrogen content value of grains which was estimated from N analysis. The nitrogen content in grains was determined by modified Micro-Kjeldhal's method (Subbiah and Asija 1956). An oven dried sample of 0.5 g was subjected to wet digestion using 10 ml concentrated sulphuric acid plus a pinch of digestion mixture (potassium sulphate + copper sulphate + selenium powder + mercury oxide). Digested material was taken in a 50 ml volumetric flask and made the volume 50 ml by using distilled water. In the distillation flask of Micro-Kjeldhal's assembly, 5 ml of distilled sample was taken and 10 ml of sodium hydroxide (NaOH) was poured into tube. On the other side of apparatus, titration flask containing 10 ml boric acid was put and digestion was continued until the appearance of green colour of boric acid. Then distilled sample was titrated against N/50 sulphuric acid until the appearance of purple colour. Volume of N/50 H_2SO_4 used was recorded for calculation of N content.

Protein conent in grains = N content in grains × 6.25

3.10.2 Oil in grains

The oil content in grains was estimated with MQC benchtop NMR Analyser (Oxford instruments, UK) as per method given by Alexander *et al* (1967).

3.11 ECONOMICS

3.11.1 Gross returns

The gross returns were calculated on the basis of minimum support price of maize and the prevailing market rate of maize stover.

3.11.2 Net returns

The net returns were calculated by subtracting the total cost of cultivation for raising maize crop from the gross returns.

3.11.3 Benefit cost ratio

It was calculated by dividing net returns with the total cost of cultivation involved in different operations and for raising maize crop.

3.12 SOIL PROPERTIES, PHYSIO-CHEMICAL ANALYSIS

Soil analysis

Composite soil sample from 0-15 cm depth was taken from the experimental field before sowing of the maize crop. These samples were air dried under shade and ground with the help of wooden pestle and mortar to pass through 0.5 mm sieve. The ground samples were mixed thoroughly and analyzed for available nitrogen, phosphorus and potassium.

3.12.1 Available soil N

Available soil nitrogen was determined by alkaline potassium permanganate method as described by Subbiah and Asija (1956). Soil was treated with an excess of alkaline-$KMnO_4$ and ammonia thus evolved was absorbed in a standard acid. The excess of the acid was titrated with standard alkali by using methyl red indicator. From the volume of standard acid used for absorption of ammonia, the amount of N in the soil sample was worked out.

3.12.2 Available soil P

It was determined by the 0.5 M sodium bicarbonate method described by Olsen *et al* (1954). Soil was shaken with extracting reagent (sodium bicarbonate) for half an hour. Then the clear filtered soil extract was treated with ammonia molybdate, complexing agent. In the presence of reducing agent (ascorbic acid) the soil extract gave blue colour. The intensity of the blue colour was measured with a spectrophotometer at a wavelength of 760 nm using red filter. With the help of standard curve, the amount of P present in soil samples was calculated.

3.12.3 Available soil K

Method given by Merwin and Peech (1950) was used to determine available K in soil samples. The index of K availability is the sum of exchangeable and water soluble potassium. The extraction of K was accomplished by using neutral ammonium acetate solution as the extractant. The extract, thus obtained was tested for its available potassium content with the help of Flame-photometer.

3.13 STATISTICAL ANALYSIS

The data on weed density and DMA of weeds were subjected to square root transformation $\sqrt{x+1}$ before statistical analysis. All the data were statistically analyzed by factorial RBD using the SAS Proc GLM (SAS 9.3). The treatment comparisons were made at 5 per cent level of significance by using Duncun's Multiple Range Test (DMRT). The split up of degrees of freedom for different sources of variation is given in table 3.4.

Table 3.4 Analysis of variance (ANOVA)

Source of variation	**Degrees of freedom (d.f.)**	
Replications (r)	(r-1)=	2
Straw mulch (a)	(a-1)=	2
Weed control (b)	(b-1)=	5
r× straw mulch	(r-1)(a-1)=	4
r× weed control	(r-1)(b-1)=	10
Straw mulch ×weed control	(a-1)(b-1)=	10
Error	(r-1)(a-1)(b-1)=	20
Total	(r×a×b-1)=	53

CHAPTER IV

RESULTS AND DISCUSSION

A field experiment "**Weed management in maize (*Zea mays* L.) using straw mulch and herbicides**" was conducted at Students' Research Farm, Department of Agronomy, PAU, Ludhiana and Research Farm, PAU Regional Research Station, Gurdaspur during *kharif* 2017. The results obtained from the investigation are described in this chapter.

4.1 Weed parameters

Weed species

The predominant weed species observed at the experimental site of Ludhiana were *Dactyloctenium aegyptium, Eleusine indica, Commelina benghalensis, Eragrostis tenella, Digitaria sanguinalis, Acrachne racemosa* and *Echinochloa colona* as grasses, *Trianthema portulacastrum, Portulaca oleracea, Digera arvensis* and *Mollugo nudicaulis* as broadleaf weeds and *Cyperus rotundus* and *Cyperus compressus* as sedges whereas, at Gurdaspur, the predominant weed species recorded were *Dactyloctenium aegyptium, Eleusine indica, Commelina benghalensis, Cynodon dactylon* and *Eragrostis tenella* as grasses, *Trianthema portulacastrum, Digera arvensis, Euphorbia hirta, Alternanthera philoxeroides, Phyllanthus niruri, Amaranthus viridis, Veronica agrestis* and *Conyza stricta* as broadleaf weeds and *Cyperus rotundus* as sedges. Other weed species viz., *Sorghum halepense, Leptochloa chinensis, Brachiaria reptans, Cleome viscosa, Cucumis callosus* and *Croton sparsiflorus* were also present at lower densities at Gurdaspur. Ndam *et al* (2014), Sandhu *et al* (1999) and Singh *et al* (1998) also reported that weed species changes with location.

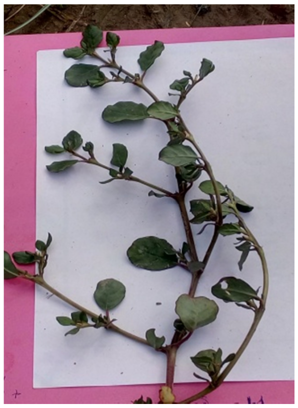
4.1.1 Weed density at 20 DAS

The data on species wise density of different weeds were recorded at both the locations and are presented in table 4.1 and 4.2. At 20 DAS, major weed species observed at Ludhiana were *Dactyloctenium aegyptium, Eleusine indica* and *Commelina benghalensis* among grasses, *Trianthema portulacastrum, Portulaca oleracea* and *Digera arvensis* among broadleaf weeds and *Cyperus rotundus* and *Cyperus compressus* were recorded as sedges whereas, at Gurdaspur, *Dactyloctenium aegyptium* and *Cynodon dactylon* as grasses, *Trianthema portulacastrum, Digera arvensis, Alternanthera philoxeroides* and *Amaranthus viridis* were among broadleaf weeds and only *Cyperus rotundus* was recorded as sedges. *Eleusine indica, Commelina benghalensis* and *Euphorbia hirta* were also present at lower densities at Gurdaspur. Pandey *et al* (2001) also reported that *Cyperus rotundus* was the most dominant weed among sedges in maize fields. Whereas at Pantnagar, *Echinochloa colona, Trianthema portulacastrum, Cyperus rotundus* and *Eleusine indica* were observed as dominant weed species in maize fields during *kharif* season (Singh and Prasad 1994).

The data showed that at both the locations density of different weed species was significantly influenced by straw mulch treatments. Straw mulch caused significant reduction in the density of all weed species as compared to no mulch treatment. Application of 9.0 t ha^{-1} mulch resulted in minimum density of *D. aegyptium, C. benghalensis, D. arvensis, C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, D. arvensis, A. philoxeroides, A.viridis* and *C. rotundus* at Gurdaspur as compared to 6.25 t ha^{-1} and no mulch treatments. Similarly, application of both 6.25 t ha^{-1} and 9.0 t ha^{-1} mulch recorded statistically similar and significantly lower density of *E. indica, T. portulacastrum* and *P. oleracea* at Ludhiana and *C. dactylon* and *T. portulacastrum* at Gurdaspur as compared to no mulch treatment. Thus, the data showed that initial flush of *D. aegyptium, C. benghalensis, D. arvensis, C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, D. arvensis, A. philoxeroides, A. viridis* and *C. rotundus* at Gurdaspur was controlled with 9.0 t ha^{-1} mulch but *E. indica, T. portulacastrum* and *P. oleracea* at Ludhiana and *C. dactylon* and *T. portulacastrum* at Gurdaspur were controlled with the application of 6.25 t ha^{-1} mulch. Uwah and Iwo (2011) also observed that straw mulch recorded significantly less weed density in comparison to no mulch.

Different weed control treatments significantly influenced the weed density at 20 DAS (Table 4.1 and 4.2). Minimum density of all weeds was recorded under weed free treatment whereas maximum density was observed under unweeded check. Among the herbicides, atrazine 1.0 kg ha^{-1} resulted in significantly less density of *D. aegyptium, C. benghalensis, C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, D. arvensis, A. philoxeroides* and *C. rotundus* at Gurdaspur in comparison to its lower dose, but the later one also significantly controlled the density of *D. aegyptium, D. arvensis* and *C. compressus* at Ludhiana and *D. aegyptium* and *D. arvensis* at Gurdaspur as compared to unweeded check. The density of *C. dactylon* at Gurdaspur was not significantly influenced by different weed control treatments. Thus, the results indicated that initial flush of *D. aegyptium, C. benghalensis, A. philoxeroides, C. rotundus* and *C. compressus* were controlled with the application of atrazine at 1.0 kg ha^{-1} within 2 days of sowing, whereas its lower dose applied within 2 days of sowing effectively controlled *E. indica, T. portulacastrum, A. viridis, P. oleracea* and *D. arvensis*. The results are corroborated with the research findings of Chopra and Angiras (2008).

The data on total weed density recorded at Ludhiana and Gurdaspur are presented in table 4.3 which showed that total weed density was significantly influenced by straw mulch and weed control treatments. Application of straw mulch caused significant reduction in total weed density as compared to no mulch treatment. It was observed that at both the locations, application of 9.0 t ha^{-1} mulch recorded significantly less density of grasses (15 and 5 m^{-2}), broadleaf weeds (2 and 4 m^{-2}) and sedges (40 and 99 m^{-2}) as compared to 6.25 t ha^{-1} and no



Trianthema portulacastrum

Portulaca oleracea

Digera arvensis

Mollugo nudicaulis

Euphorbia hirta

Alternanthera philoxeroides

Amaranthus viridis

Phyllanthus niruri

Plate 1a. Major weed species present in the experimental field



Dactyloctenium aegyptium *Eleusine indica* *Commelina benghalensis*



Eragrostis tenella *Digitaria sanguinalis* *Cynodon dactylon*


Cyperus rotundus *Cyperus compressus*

Plate 1b. Major weed species present in the experimental field

Table 4.1 Effect of straw mulch and weed control treatments on species-wise weed density in maize at 20 DAS (Ludhiana)

Treatment	Weed density (number m^{-2})							
	Grasses			BLWs*			Sedges	
	D. aegyptium	*E. indica*	*C. benghalensis*	*T. portulacastrum*	*P. oleracea*	*D. arvensis*	*C. rotundus*	*C. compressus*
Straw mulch								
No mulch	12.05(185)c	3.57(18)b	2.83(8)c	2.02(4)b	1.50(2)b	2.96(9)c	4.66(24)c	11.51(167)c
PSM 6.25 t ha^{-1}	4.50(26)b	1.00(0)a	2.08(4)b	1.00(0)a	1.00(0)a	2.05(4)b	3.90(18)b	5.86(46)b
PSM 9.0 t ha^{-1}	3.29(13)a	1.00(0)a	1.54(2)a	1.00(0)a	1.00(0)a	1.69(2)a	3.54(15)a	4.34(25)a
Weed control								
Atrazine at 1.0 kg ha^{-1}	3.11(18)b	1.00(0)a	1.66(3)b	1.00(0)a	1.00(0)a	1.41(1)b	1.86(4)b	2.93(15)b
Atrazine at 0.8 kg ha^{-1}	6.64(53)c	1.14(0.4)a	2.32(5)c	1.00(0)a	1.00(0)a	1.99(4)b	5.30(28)c	7.32(64)c
Tembotrione at 0.110 kg ha^{-1}	9.66(126)d	2.66(12)b	2.50(6)cd	1.75(3)b	1.30(1)b	2.99(8)c	5.19(26)c	10.83(134)d
Tembotrione at 0.088 kg ha^{-1}	9.64(125)d	2.68(12)b	2.68(7)cd	1.66(2)b	1.41(1)b	2.98(8)c	5.40(29)c	10.69(131)d
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	9.64(126)d	2.66(12)b	2.75(7)cd	1.67(3)b	1.29(1)b	3.03(9)c	5.44(29)c	10.64(131)d

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.2 Effect of straw mulch and weed control treatments on species-wise weed density in maize at 20 DAS (Gurdaspur)

Treatment	Weed density (number m^{-2})						
	Grasses		BLWs				Sedges
	D. aegyptium	***C. dactylon***	***T. portulacastrum***	***D. arvensis***	***A. philoxeroides***	***A. viridis***	***C. rotundus***
Straw mulch							
No mulch	3.49(15)c	2.26(5)b	1.96(4)b	1.72(2)c	2.35(5)c	1.92(4)c	13.40(212)c
PSM 6.25 t ha^{-1}	2.64(8)b	1.53(2)a	1.22(0.6)a	1.42(1)b	1.17(0.4)b	1.55(2)b	10.13(120)b
PSM 9.0 t ha^{-1}	1.85(3)a	1.43(1)a	1.17(0.4)a	1.17(0.4)a	1.00(0)a	1.31(1)a	9.18(99)a
Weed control							
Atrazine at 1.0 kg ha^{-1}	1.72(3)b	1.71(3)a	1.00(0)a	1.00(0)a	1.20(0.6)b	1.00(0)a	10.62(116)b
Atrazine at 0.8 kg ha^{-1}	1.91(4)c	2.13(4)a	1.00(0)a	1.17(0.4)b	1.58(2)c	1.00(0)a	13.77(191)c
Tembotrione at 0.110 kg ha^{-1}	3.86(16)d	2.16(4)a	2.03(3.5)b	1.88(3)c	1.83(3)d	2.17(4)b	14.02(201)d
Tembotrione at 0.088 kg ha^{-1}	4.02(18)d	2.18(4)a	2.02(3.4)b	1.89(3)c	1.84(3)d	2.10(3)b	13.98(200)d
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0) a	1.00(0)a
Unweeded check	3.85(15)d	2.17(4)a	2.01(3.4)b	1.93(3)c	1.84(3)d	2.27(4)b	14.06(201)d

- Data were subjected to square root transformation √x+1. Original values are in parentheses.
- In a column, means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.3 Effect of straw mulch and weed control treatments on total weed density in maize at 20 DAS

Treatment	Weed density (number m^{-2})							
	Ludhiana				Gurdaspur			
	Grasses	BLWs*	Sedges	Total	Grasses	BLWs*	Sedges	Total
Straw mulch								
No mulch	12.82(211)c	3.60(15)c	12.37(191)c	18.06(417)c	4.43(23)c	4.27(24)c	13.40(212)c	14.73(259)c
PSM 6.25 t ha^{-1}	4.81(30)b	2.05(4)b	6.90(64)b	8.42(98)b	3.04(10)b	2.74(9)b	10.13(120)b	10.85(139)b
PSM 9.0 t ha^{-1}	3.49(15)a	1.69(2)a	5.46(40)a	6.45(57)a	2.34(5)a	2.06(4)a	9.19(99)a	9.58(108)a
Weed control								
Atrazine at 1.0 kg ha^{-1}	3.27(21)b	1.41(1)b	3.21(19)b	4.37(41)b	2.45(5)b	1.16(0.5)b	10.62(116)b	10.87(122)b
Atrazine at 0.8 kg ha^{-1}	7.00(58)c	1.99(4)c	9.13(92)c	11.61(154)c	2.80(7)c	1.94(4)c	11.77(142)c	12.19(153)c
Tembotrione at 0.110 kg ha^{-1}	10.29(144)d	3.45(12)d	12.04(160)d	16.28(316)d	4.36(20)d	4.57(23)d	14.02(201)d	15.36(244)d
Tembotrione at 0.088 kg ha^{-1}	10.34(144)d	3.40(11)d	12.03(160)d	16.28(315)d	4.52(22)d	4.58(22)d	13.98(200)d	15.37(244)d
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	10.35(145)d	3.43(13)d	12.04(160)d	16.31(318)d	4.50(22)d	4.87(26)d	14.06(202)d	15.54(250)d

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

mulch treatments. Similarly, application of 6.25 t ha^{-1} mulch also resulted in significantly less density of grasses (30 and 10 m^{-2}), broadleaf weeds (4 and 9 m^{-2}) and sedges (64 and 120 m^{-2}) as compared to no mulch treatment. Highest density of grasses (211 and 23 m^{-2}), broadleaf weeds (15 and 24 m^{-2}) and sedges (191 and 212 m^{-2}) was recorded in no mulch treatment. Shah *et al* (2014) also reported minimum number of weeds under mulch treatments in comparison to unweeded check.

Among herbicides, higher dose of atrazine effectively controlled total weeds (41 and 122 m^{-2}) in comparison to atrazine at lower dose (154 and 153 m^{-2}) and unweeded check (318 and 250 m^{-2}), later two also differed significantly. However, the lowest total weed density was observed under the weed free treatment. Thus, the data indicated that application of atrazine at 1.0 kg ha^{-1} effectively controlled the weed flora at 20 DAS at both locations. Chopra and Angiras (2008) also reported that total weed density was significantly reduced with pre-emergence application of atrazine as compared to unweeded check.

4.1.2 Weed density at 40 DAS

Species wise density of different weeds at 40 DAS was recorded at both the locations and the data are presented in table 4.4 and 4.5. The weed species observed at Ludhiana were *D. aegyptium, E. indica, C. benghalensis, E. tenella, D. sanguinalis*, *A. racemosa, E. crusgalli* and *E. colona* as grasses, *T. portulacastrum, D. arvensis* and *M. nudicaulis* as broadleaf weeds and *C. rotundus* and *C. compressus* as sedges whereas, at Gurdaspur, *D. aegyptium, E. indica, C. benghalensis* and *C. dactylon* as grasses, *T. portulacastrum, D. arvensis, E. hirta, A. philoxeroides* and *P. niruri* were among broadleaf weeds and only *C. rotundus* as sedges. Similar findings with respect to change in weed flora at different locations was observed by Ndam *et al* (2014), Singh *et al* (1998) and Rout and Satapathy (1996).

The data showed that straw mulch significantly influenced the density of different weed species at both the locations. Application of 9.0 t ha^{-1} mulch effectively controlled *D. aegyptium, C. benghalensis, E. tenella, A. racemosa, T. portulacastrum, D. arvensis, M. nudicaulis*, *C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, C. benghalensis, C. dactylon, T. portulacastrum, D. arvensis, E. hirta, A. philoxeroides* and *C. rotundus* at Gurdaspur as compared to 6.25 t ha^{-1} and no mulch treatments irrespective of the weed control treatments. Similarly, application of paddy straw mulch both at 6.25 and 9.0 t ha^{-1} were statistically similar and significantly better in controlling the *E. indica, D. sanguinalis*, *E. colona* at Ludhiana and *E. indica, C. benghalensis and P. niruri* at Gurdaspur as compared to no mulch treatment. Thus, the data showed, the application of paddy straw mulch helped to control the weeds in maize as compared to no mulch. Uwah and Iwo (2011) also reported that straw mulch significantly lowered density of different weed species in comparison to no mulch.

Different weed control treatments significantly affected the species-wise density at

Plate 3. Atrazine at 1.0 kg ha $^{-1}$ pre-emergence with and without straw mulch application

Plate 4. Atrazine at 0.8 kg ha $^{-1}$ pre-emergence with and without straw mulch application

Plate 5. Tembotrione at 0.110 kg ha $^{-1}$ post-emergence with and without straw mulch application

Plate 6. Tembotrione at 0.088 kg ha^{-1} post-emergence with and without straw mulch application

Plate 7. Bleaching symptoms with application of tembotrione

Plate 8. Weed free with and without straw mulch application

both the locations at 40 DAS (Table 4.4 and 4.5). Minimum density of all the weed species was recorded under weed free treatment whereas maximum density was observed under unweeded check irrespective of the straw mulch treatments. Among the herbicide treatments, tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) gave significantly better control of *D. aegyptium, E. indica, E. tenella, D. sanguinalis*, *A. racemosa, E. colona, D. arvensis, C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, C. dactylon, A. philoxeroides, P. niruri* and *C. rotundus* at Gurdaspur in comparison to atrazine at both doses (0.8 and 1.0 kg ha^{-1}). Similarly, higher dose of atrazine also effectively controlled *E. indica, C. benghalensis, E. crusgalli, T. portulacastrum* and *M. nudicaulis* at Ludhiana and *E. indica, C. benghalensis, T. portulacastrum, D. arvensis* and *E. hirta* in comparison to its lower dose and unweeded check at Gurdaspur. Thus, the results indicated that tembotrione at both doses were found very effective in controlling different species of weeds in comparison to atrazine at both doses. Rana *et al* (2017) also observed that post emergence application of tembotrione effectively controlled the population of *Echinochloa colona, Commelina benghalensis, Polygonum alatum* and *Ageratum conyzoides*.

Dactyloctenium aegyptium

The interaction was significant with respect to the density of *D. aegyptium* at 40 DAS (Table 4.6 and Table 4.8). The data showed that at Ludhiana and Gurdaspur, lowest density of *D. aegyptium* was recorded under weed free treatment and highest under unweeded check as compared to all other weed control treatments irrespective of paddy straw mulch treatments. Application of 9.0 t ha^{-1} mulch resulted in significantly lower density of *D. aegyptium* as compared to 6.25 t ha^{-1} and no mulch treatments irrespective of the herbicide treatments. Similarly, application of 6.25 t ha^{-1} mulch also recorded significantly lower density of *D. aegyptium* than no mulch treatment irrespective of the herbicide treatments at both the locations. Among the herbicide-mulch combinations, lowest density of *D. aegyptium* was recorded with the tembotrione at both doses (with nil density) each in combination with 9.0 t ha^{-1} mulch and both the above combinations were significantly better in comparison to all other herbicide-mulch combinations in controlling the density of *D. aegyptium*. The data further revealed that atrazine at lower dose in combination with 6.25 t ha^{-1} mulch recorded significantly lower density of *D. aegyptium* as obtained under its higher dose without mulch. Similarly, lower dose of atrazine in combination with paddy straw mulch at 9.0 t ha^{-1} recorded significantly lower density of *D. aegyptium* as obtained under atrazine at higher dose in combination with 6.25 t ha^{-1} mulch. Paddy straw mulch at 9.0 t ha^{-1} without any herbicide (unweeded check) resulted in significantly lower density of *D. aegyptium* as obtained under atrazine at higher dose without mulch. Under no mulch treatments, both tembotrione and atrazine at lower doses gave comparatively more density of *D. aegyptium* than their respective higher doses, however both herbicides in combination with 6.25 t ha^{-1} mulch recorded

Table 4.4 Effect of straw mulch and weed control treatments on species-wise weed density in maize at 40 DAS (Ludhiana)

Treatment	Weed density (number m^{-2})												
	Grasses								BLWs*			Sedges	
	D. aegyptium	*E. indica*	*C. benghalensis*	*E. tenella*	*D. sanguinalis*	*A. racemosa*	*E. crusgalli*	*E. colona*	*T. portulacastrum*	*D. arvensis*	*M. nudicaulis*	*C. rotundus*	*C. compressus*
Straw mulch													
No mulch	4.92(31)c	1.39(1)b	2.74(8)c	3.47(13)c	2.56(8)b	1.75(3)c	1.56(2)c	2.49(12)b	2.16(5)c	2.19(6)c	1.83(6)c	6.78(62)c	5.48(45)c
PSM 6.25 t ha^{-1}	2.40(6)b	1.00(0)a	2.45(6)b	1.93(4)b	1.00(0)a	1.22(0.7)b	1.22(0.7)b	1.34(1)a	1.19(0.5)b	1.58(2)b	1.20(0.7)b	4.40(27)b	3.36(15)b
PSM 9.0 t ha^{-1}	1.47(2)a	1.00(0)a	1.68(2)a	1.15(0.4)a	1.00(0)a	1.00(0)a	1.00(0)a	1.15(0.4)a	1.17(0.4)a	1.40(1)a	1.02(0.1)a	4.09(23)a	1.51(3)a
Weed control													
Atrazine at 1.0 kg ha^{-1}	3.31(13)c	1.00(0)a	2.37(5)b	2.33(6)c	1.66(3)b	1.30(0.9)b	1.17(0.4)a	1.44(1)b	1.17(0.4)a	1.91(3)b	1.00(0)a	4.61(25)c	2.65(8)b
Atrazine at 0.8 kg ha^{-1}	4.02(20)d	1.30(0.9)b	2.95(8)c	2.75(8)d	2.09(6)c	1.56(2)b	1.59(2)b	1.46(1)b	1.64(2)b	2.51(6)c	1.00(0)a	7.77(62)d	6.23(43)c
Tembotrione at 0.110 kg ha^{-1}	1.97(4)b	1.00(0)a	2.02(4)b	1.77(3)b	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.13(0.3)a	1.00(0)a	1.00(0)a	3.09(10)b	2.53(7)b
Tembotrione at 0.088 kg ha^{-1}	1.90(3)b	1.00(0)a	1.95(3)b	1.79(3)b	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.13(0.3)a	1.00(0)a	1.00(0)a	3.68(13)b	1.58(2)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	5.40(36)e	1.30(0.9)b	3.47(12)d	3.46(13)e	2.37(8)d	2.09(4)c	1.80(3)c	4.07(24)c	2.86(8)c	2.92(8)d	3.10(13)b	10.39(112)d	6.72(66)d
Interaction	S	NS	NS	S	S	NS	NS	S	S	NS	NS	S	S

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.5 Effect of straw mulch and weed control treatments on species-wise weed density in maize at 40 DAS (Gurdaspur)

Treatment	Weed density (number m^{-2})									
	Grasses				BLWs*					Sedges
	D. aegyptium	*E. indica*	*C. benghalensis*	*C. dactylon*	*T. portulacastrum*	*D. arvensis*	*E. hirta*	*A. philoxeroides*	*P. niruri*	*C. rotundus*
Straw mulch										
No mulch	2.46(8)c	1.25(0.9)b	1.29(0.9)c	1.95(3)c	1.47(2)c	1.32(1)c	1.18(0.7)a	1.55(2)c	1.55(2)b	12.67(196)c
PSM 6.25 t ha^{-1}	1.75(3)b	1.00(0)a	1.14(0.5)b	1.46(2)b	1.09(0.2)b	1.15(0.3)b	1.07(0.2)a	1.41(1)b	1.11(0.3)a	10.97(146)b
PSM 9.0 t ha^{-1}	1.35(1)a	1.00(0)a	1.00(0)a	1.26(0.7)a	1.00(0)a	1.00(0)a	1.00(0)a	1.11(0.3)a	1.00(0)a	8.24(82)a
Weed control										
Atrazine at 1.0 kg ha^{-1}	1.88(3)b	1.00(0)a	1.00(0)a	1.57(2)b	1.03(0.1)a	1.00(0)a	1.00(0)a	1.44(1)b	1.30(0.9)b	12.77(167)c
Atrazine at 0.8 kg ha^{-1}	2.16(4)c	1.30(0.9)b	1.17(0.4)b	1.59(2)b	1.17(0.4)b	1.14(0.4)a	1.00(0)a	1.62(2)b	1.44(1)b	13.29(181)d
Tembotrione at 0.110 kg ha^{-1}	1.17(0.4)a	1.00(0)a	1.00(0)a	1.17(0.4)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	9.75(97)b
Tembotrione at 0.088 kg ha^{-1}	1.17(0.4)a	1.00(0)a	1.00(0)a	1.20(0.5)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	9.73(96)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	3.74(16)d	1.80(3)c	1.41(1)c	2.67(6)c	1.76(3)c	1.67(2)b	1.50(2)b	2.08(4)c	1.59(2)c	17.23(305)e
Interaction	S	NS	NS	S	S	NS	NS	NS	NS	S

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.6 Interactive effect of straw mulch and weed control treatments on density of *D. aegyptium*, *E. tenella* and *D. sanguinalis* in maize at 40 DAS (Ludhiana)

Treatment	Weed density (number m^{-2})								
	D. aegyptium			*E. tenella*			*D. sanguinalis*		
	No mulch	**PSM 6.25 t ha^{-1}**	**PSM 9.0 t ha^{-1}**	**No mulch**	**PSM 6.25 t ha^{-1}**	**PSM 9.0 t ha^{-1}**	**No mulch**	**PSM 6.25 t ha^{-1}**	**PSM 9.0 t ha^{-1}**
Atrazine at 1.0 kg ha^{-1}	5.79(33)e	2.75(7)c	1.38(1)b	3.49(11)e	2.49(5)c	1.00(0)a	2.98(8)b	1.00(0)a	1.00(0)a
Atrazine at 0.8 kg ha^{-1}	7.03(49)f	3.41(11)d	1.61(2)b	4.28(17)f	2.97(8)d	1.00(0)a	4.27(17)c	1.00(0)a	1.00(0)a
Tembotrione at 0.110 kg ha^{-1}	2.70(6)c	1.72(2)b	1.00(0)a	3.31(10)d	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Tembotrione at 0.088 kg ha^{-1}	3.18(9)c	1.52(1)b	1.00(0)a	3.36(10)d	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	9.36(87)g	4.01(15)d	2.82(7)c	5.37(28)g	3.11(9)d	1.90(3)b	5.12(25)d	1.00(0)a	1.00(0)a

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- Means followed by common letters do not vary significantly at 5% level by DMRT

Table 4.7 Interactive effect of straw mulch and weed control treatments on density of *E. colona, C. rotundus* and *C. compressus* in maize at 40 DAS (Ludhiana)

Treatment	Weed density (number m^{-2})								
	E. colona			*C. rotundus*			*C. compressus*		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	1.90(3)b	1.41(1)b	1.00(0)a	7.69(59)f	3.72(13)d	3.25(10)c	3.92(15)d	3.01(8)c	1.00(0)a
Atrazine at 0.8 kg ha^{-1}	1.95(3)b	1.41(1)b	1.00(0)a	9.64(92)h	8.22(67)g	5.44(29)e	9.47(88)g	5.15(26)e	3.19(9)c
Tembotrione at 0.110 kg ha^{-1}	1.00(0)a	1.00(0)a	1.00(0)a	4.23(17)d	3.00(8)c	2.06(3)b	2.71(7)b	1.00(0)a	1.00(0)a
Tembotrione at 0.088 kg ha^{-1}	1.00(0)a	1.00(0)a	1.00(0)a	4.58(20)d	3.05(8)c	2.34(7)b	2.73(7)b	1.00(0)a	1.00(0)a
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	8.11(65)c	2.22(4)b	1.88(3)b	13.55(183)i	9.11(82)h	8.52(72)g	12.33(151)h	6.83(46)f	4.08(16)d

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- Means followed by common letters do not vary significantly at 5% level by DMRT

Table 4.8 Interactive effect of straw mulch and weed control treatments on density of *D. aegyptium, C. dactylon* and *C. rotundus* in maize at 40 DAS (Gurdaspur)

Treatment	Weed density (number m^{-2})								
	D. aegyptium			*C. dactylon*			*C. rotundus*		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	2.23(4)e	1.90(3)d	1.52(1)b	2.20(4)c	1.52(1)b	1.00(0)a	15.29(233)f	13.13(171)e	9.89(97)c
Atrazine at 0.8 kg ha^{-1}	2.75(7)f	2.03(3)d	1.52(1)b	2.24(4)c	1.52(1)b	1.00(0)a	15.91(253)f	13.60(184)e	10.36(107)c
Tembotrione at 0.110 kg ha^{-1}	1.52(1)b	1.00(0)a	1.00(0)a	1.52(1)b	1.00(0)a	1.00(0)a	11.59(133)d	10.29(105)c	7.37(53)b
Tembotrione at 0.088 kg ha^{-1}	1.72 (2)c	1.00(0)a	1.00(0)a	1.52(1)b	1.00(0)a	1.00(0)a	11.61(134)d	10.18(103)c	7.39(54)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	6.30(39)g	2.87(7)f	2.07(3)d	3.20(9)e	2.73(7)d	2.07(3)c	20.62(425)h	17.65(311)g	13.43(179)e

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- Means followed by common letters do not vary significantly at 5% level by DMRT

significantly lower density of *D. aegyptium* than their higher doses each under no mulch treatments. The data further revealed that for getting lowest density of *D. aegyptium* in maize, tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) can be applied in combination with 9.0 t ha^{-1} mulch. Thus, the results showed that application of paddy straw mulch at 9.0 t ha^{-1} helped in lowering 20 % herbicide dose of atrazine and tembotrione.

Eragrostis tenella

This weed was observed only at Ludhiana site at 40 DAS. The interaction was significant (Table 4.6) which showed that weed free treatment recorded lowest density of *E. tenella* and it was highest under unweeded check as compared to all other weed control treatments irrespective of straw mulch treatments. Both 6.25 t ha^{-1} and 9.0 t ha^{-1} mulch levels recorded significantly less density of *E. tenella* in comparison to no mulch irrespective of the herbicide treatments. The data further revealed that *E. tenella* was effectively controlled by tembotrione at both doses (0.088 and 0.110 kg ha^{-1}), weed free treatment, atrazine at both doses (1.0 and 0.8 kg ha^{-1}) each in combination with paddy straw mulch at 9.0 t ha^{-1} and tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) and weed free treatment each in combination with 6.25 t ha^{-1} mulch and weed free under no mulch treatment. All the above mentioned combinations were significantly better in comparison to all other herbicide-mulch combinations. The data further indicated that atrazine at lower dose in combination with 6.25 t ha^{-1} paddy straw mulch recorded statistically lower density of *E. tenella* as obtained under its higher dose without mulch. Similarly, atrazine at lower dose in combination with paddy straw mulch at 9.0 t ha^{-1} recorded significantly lower density of *E. tenella* as obtained under atrazine at both doses (1.0 and 0.8 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch, thus indicates the beneficial effect of mulch. Application of 6.25 t ha^{-1} mulch without any herbicide (unweeded check) resulted in significantly less density of *E. tenella* as obtained under atrazine at 1.0 kg ha^{-1} in combination with no mulch. Under no mulch treatments, tembotrione at 0.110 kg ha^{-1} gave comparatively lower density of *E. tenella* than all other herbicide treatments, however tembotrione at 0.088 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch recorded significantly lower density of *E. tenella* than tembotrione at 0.110 kg ha^{-1} without mulch. Thus, the results showed that both tembotrione and atrazine at lower doses in combination with paddy straw mulch treatments were more effective as compared to their higher doses without mulch in reducing the density of *E. tenella.*

Digitaria sanguinalis

The density of *D. sanguinalis* at 40 DAS was significantly affected by straw mulch and weed control treatments (Table 4.6). This weed was only observed at Ludhiana location. The interaction effects indicated that all weed control treatments in combination with both 6.25 and 9.0 t ha^{-1} mulch and tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) under no mulch treartment effectively lowered the density of *D. sanguinalis* as compared to its density in unweeded check, atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg ha^{-1} under no mulch treatment. The data further revealed that the density of *D. sanguinalis* was significantly less under higher dose of atrazine in comparison to its lower dose and unweeded check under no mulch treatment, later two treatments also differed significantly with each other. Furthermore, lower dose of atrazine in combination with 6.25 t ha^{-1} paddy straw mulch resulted in significantly lower density in comparison to its higher dose without mulch. So, lower levels of atrazine and tembotrione in combination with straw mulch also proved very effective for controlling *D. sanguinalis*.

Echinochloa colona

This weed was observed only at Ludhiana site. Straw mulch and weed control treatments significantly influenced the density of *E. colona* at 40 DAS (Table 4.7). The data revealed that application of 9.0 t ha^{-1} mulch significantly reduced density of *E. colona* in comparison to no mulch irrespective of all herbicide treatments except under both doses of tembotrione. Among herbicide treatments, tembotrione at both doses, weed free treatment, atrazine at both doses each in combination with paddy straw mulch at 9.0 t ha^{-1} and tembotrione at both doses and weed free treatment each in combination with 6.25 t ha^{-1} mulch or without mulch effectively controlled *E. colona* as compared to all other treatment combinations. The data further revealed that application of atrazine at both doses in combination with 6.25 t ha^{-1} mulch and without mulch and application of both 6.25 and 9.0 t ha^{-1} mulch without any herbicide (unweeded check) resulted in statistically similar density of *E. colona* and all the above treatments were significantly better than unweeded check without mulch in controlling the density of *E. colona*. Yakadri *et al* (2015) also found *Echinochloa colona* as most dominant weed species in maize.

Cyperus rotundus

The interaction was significant with respect to the density of *C. rotundus* at both the locations (Table 4.7 and 4.8). At Ludhiana and Gurdaspur, the data indicated that application of both 6.25 t ha^{-1} and 9.0 t ha^{-1} mulch resulted in significantly lower density of *C. rotundus* in comparison to no mulch irrespective of weed control treatments. The data showed that lowest density of *C. rotundus* was recorded under weed free treatment and highest under unweeded check as compared to all other weed control treatments irrespective of straw mulch treatments. Among the herbicide treatments, lowest density of *C. rotundus* was observed under tembotrione at both doses each in combination with 9.0 t ha^{-1} mulch and both the above treatments were significantly better than all other herbicide-mulch combinations in controlling the density of *C. rotundus* at both the locations. These treatments were followed by tembotrione at both doses each in combination with 6.25 t ha^{-1} mulch and atrazine at higher dose in combination with 9.0 t ha^{-1} mulch for lowering the density of *C. rotundus*.

At both the locations, it was observed that significantly less density of *C. rotundus* was recorded under atrazine at lower dose in combination with paddy straw mulch at 9.0 t ha^{-1} in comparison to its higher dose without mulch. Similarly, tembotrione at 0.088 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch recorded significantly less density of *C. rotundus* as compared to tembotrione at 0.110 kg ha^{-1} without mulch at both the locations, thus indicating the advantage of straw mulch in controlling *C. rotundus*. Significantly higher density of *C. rotundus* was observed in unweeded check under no mulch treatment as compared to all other treatment combinations. Under no mulch treatments, lowest density of *C. rotundus* was recorded under weed free treatment which was followed by tembotrione at 0.110 kg ha^{-1}, tembotrione at 0.088 kg ha^{-1}, atrazine at 1.0 kg ha^{-1}, atrazine at 0.8 kg ha^{-1} and unweeded check. Pandey *et al* (2001) and Singh and Prasad (1994) also reported that *Cyperus rotundus* as the most dominant weed among sedges in maize fields.

Cyperus compressus

This weed was observed only at Ludhiana site. The density of *C. compressus* at 40 DAS was significantly influenced by straw mulch and weed control treatments (Table 4.7). The interaction effects indicated that application of both 6.25 and 9.0 t ha^{-1} mulch resulted in significantly less density of *C. compressus* as compared to no mulch treatment irrespective to the weed control treatments. The data showed that significantly less density of *C. compressus* was observed under weed free treatment and high density of *C. compressus* under unweeded check as compared to all other weed control treatments irrespective to straw mulch treatments. The data further showed that among the herbicide treatments, *C. compressus* was effectively controlled by application of atrazine at higher dose and tembotrione at both doses each in combination with 9.0 t ha^{-1} mulch, tembotrione at both doses, each in combination with 6.25 t ha^{-1} mulch as compared to all other herbicide-mulch combinations. Among the herbicides under no mulch treatments, lowest density of *C. compressus* was recorded under tembotrione at 0.110 kg ha^{-1} which was followed by tembotrione at 0.088 kg ha^{-1}, atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg ha^{-1}. The data further indicated that atrazine at lower dose in combination with paddy straw mulch at 9.0 t ha^{-1} recorded significantly less density of *C. compressus* in comparison to its higher dose without mulch. Similarly, tembotrione at 0.088 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch recorded significantly less density of *C. compressus* as compared to tembotrione at 0.110 kg ha^{-1} without mulch.

Cynodon dactylon

This weed was observed only at Gurdaspur site at 40 DAS. The interaction was significant with respect to the density of *C. dactylon* (Table 4.8). The data indicated that application of 6.25 and 9.0 t ha^{-1} mulch recorded significantly less density of *C. dactylon* in comparison to no mulch irrespective of weed control treatments except weed free treatment. The lowest density of *C. dactylon* was recorded under weed free treatment and highest under unweeded check as compared to all other weed control treatments irrespective of straw mulch treatments. The data further revealed that *C. dactylon* was effectively controlled by tembotrione at both doses, weed free treatment and atrazine at both doses each in combination with straw mulch at 9.0 t ha^{-1} and tembotrione at both doses and weed free treatment each in combination with 6.25 t ha^{-1} mulch and all the above combinations were significantly better in comparison to all other herbicide-mulch combinations. The data revealed that atrazine at lower dose in combination with paddy straw mulch at 6.25 t ha^{-1} recorded significantly lower density of *C. dactylon* as obtained under its higher dose without mulch. Application of straw mulch at 9.0 t ha^{-1} without any herbicide (unweeded check) resulted in statistically similar density of *C. dactylon* as obtained under atrazine at 1.0 kg ha^{-1} without mulch. Similarly, tembotrione at 0.088 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch recorded significantly lower density of *C. dactylon* than tembotrione at 0.110 kg ha^{-1} without mulch, thus indicating the advantage of straw mulch in controlling *C. dactylon*.

Trianthema portulacastrum

The interaction was significant with respect to the density of *T. portulacastrum* (Table 4.9). This weed was observed at both the locations. At Ludhiana, the data showed that application of 6.25 t ha^{-1} and 9.0 t ha^{-1} mulch resulted in significantly lower density of *T. portulacastrum* as compared to no mulch treatment irrespective to the weed control treatments.

Table 4.9 Interactive effect of straw mulch and weed control treatments on density of *T. portulacastrum* in maize at 40 DAS

Treatment	***T. portulacastrum* (number m^{-2})**					
	Ludhiana			**Gurdaspur**		
	No mulch	**PSM 6.25 t ha^{-1}**	**PSM 9.0 t ha^{-1}**	**No mulch**	**PSM 6.25 t ha^{-1}**	**PSM 9.0 t ha^{-1}**
Atrazine at 1.0 kg ha^{-1}	1.52(1)b	1.00(0)a	1.00(0)a	1.52(1)b	1.00(0)a	1.00(0)a
Atrazine at 0.8 kg ha^{-1}	2.37(5)c	1.63(2)b	1.00(0)a	1.52(1)b	1.00(0)a	1.00(0)a
Tembotrione at 0.110 kg ha^{-1}	1.61(2)b	1.28(1)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Tembotrione at 0.088 kg ha^{-1}	1.63(2)b	1.28(1)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	4.10(16)e	2.76(7)d	1.72(2)b	2.76(7)c	1.52(1)b	1.00(0)a

- Data were subjected to square root transformation √x+1. Original values are in parentheses.
- Means followed by same letters do not vary significantly at 5% level by DMRT

The data showed that *T. portulacastrum* was effectively controlled by application of both doses of atrazine and tembotrione, weed free treatment each in combination with 6.25

and 9.0 t ha^{-1} mulch and weed free treatment without mulch. All the above treatments combinations were significantly better than all other herbicide-mulch combinations. The data further revealed that atrazine at lower dose in combination with paddy straw mulch at 6.25 t ha^{-1} and application of 9.0 t ha^{-1} mulch without any herbicide (unweeded check) recorded statistically similar density of *T. portulacastrum* as obtained under atrazine at higher dose without mulch. Tembotrione at lower dose in combination with 6.25 t ha^{-1} mulch recorded significantly less density of *T. portulacastrum* as compared to its higher dose without mulch. Highest density of *T. portulacastrum* was recorded in unweeded check under no mulch treatment. Saeed *et al* (2010) reported that *Trianthema portulacastrum*, a strong competitor of maize caused substantial yield losses depending upon intensity of infestation.

However at Gurdaspur, all the straw mulch and weed control treatment combinations effectively controlled the density of *T. portulacastrum* except by application of atrazine at both doses without mulch and unweeded check under 6.25 t ha^{-1} mulch treatments. Significantly higher density of *T. portulacastrum* was observed in unweeded check under no mulch treatment as compared to all other treatment combinations.

Total density of grasses, broadleaf weeds and sedges at 40 DAS

The interaction was significant with respect to the total density of grasses, broadleaf weeds and sedges (Table 4.10, 4.11 and Fig 4.1). The data showed that application of 9.0 t ha^{-1} mulch resulted in significantly lower density of grasses, broadleaf weeds and sedges as compared to 6.25 t ha^{-1} mulch and no mulch treatments irrespective to the herbicide treatments. Similarly, application of 6.25 t ha^{-1} mulch also recorded significantly lower density of total weeds than no mulch treatment at both the locations. Among the herbicide treatments, both at Ludhiana and Gurdaspur, lowest weed density was recorded under weed free treatment and highest under unweeded check as compared to all other weed control treatments, irrespective to straw mulch treatments. Tembotrione at both doses recorded statistically similar but comparatively lower density of grasses, broadleaf weeds and sedges as compared to atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg ha^{-1} treatments irrespective of straw mulch treatments. Among the herbicide-mulch combinations, significantly lower density of grasses, broadleaf weeds and sedges was recorded with the application of tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} each in combination with 9.0 t ha^{-1} mulch and both the above treatments were significantly better than all other herbicide combinations. The data further revealed that application of atrazine at lower dose in combination with straw mulch at 9.0 t ha^{-1} recorded significantly lower density of grasses, broadleaf weeds and sedges as obtained under atrazine at higher dose without mulch. Application of 9.0 t ha^{-1} mulch without any herbicide i.e. unweeded check resulted in significantly lower density of total weeds as obtained under atrazine at higher dose in combination with no mulch at both the locations.

Table 4.10 Interactive effect of straw mulch and weed control treatments on weed density at 40 DAS (Ludhiana)

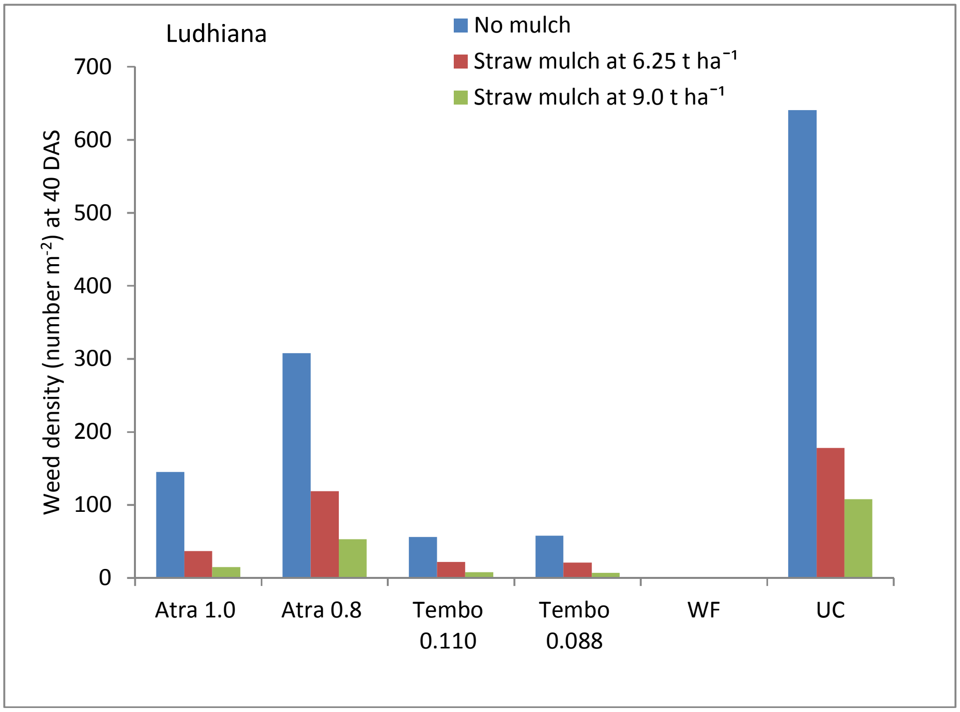
Treatment	Weed density (number m^{-2})											
	Grasses			BLWs*			Sedges			Total		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	8.14(65)f	4.41(19)c	2.13(4)b	2.76(7)c	1.73(2)b	1.52(1)b	8.61(73)f	4.11(16)c	3.25(10)b	12.09(145)h	6.89(37)e	4.62(15)c
Atrazine at 0.8 kg ha^{-1}	10.50(109)g	5.71(32)d	2.54(6)b	4.31(18)d	2.43(5)c	1.99(3)b	13.48(181)h	9.16(82)f	6.73(44)e	15.45(308)I	7.86(119)f	5.52(53)d
Tembotrione at 0.110 kg ha^{-1}	5.13(26)c	2.74(7)b	1.00(0)a	1.90(3)b	1.61(2)b	1.00(0)a	5.26(27)d	3.67(13)c	3.00(8)b	7.54(56)e	4.67(22)c	3.00(8)b
Tembotrione at 0.088 kg ha^{-1}	5.24(27)c	2.55(6)b	1.00(0)a	1.99(3)b	1.61(2)b	1.00(0)a	5.35(28)d	3.72(13)c	2.75(7)b	7.57(58)e	4.58(21)c	2.75(7)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	15.50(240)h	6.70(44)e	4.60(20)c	8.21(67)e	4.15(16)d	2.56(6)c	18.29(334)i	10.89(118)g	9.11(82)f	20.99(641)j	11.06(178)g	7.46(108)e

- Data were subjected to square root transformation √x+1. Original values are in parentheses.
- Means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.11 Interactive effect of straw mulch and weed control treatments on weed density at 40 DAS (Gurdaspur)

Treatment	Weed density (number m^{-2})											
	Grasses			BLWs*			Sedges			Total		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	3.21(9)e	2.73(7)d	1.52(1)b	3.00(8)d	1.46(1)b	1.46(1)b	15.29(233)f	13.13(171)e	9.89(97)c	15.84(250)f	13.41(179)e	9.99(99)c
Atrazine at 0.8 kg ha^{-1}	4.86(23)f	3.36(11)e	2.24(4)c	3.60(12)e	2.14(4)c	1.52(2)b	15.91(253)f	13.60(184)e	10.36(107)c	16.95(288)g	13.81(199)e	10.64(113)c
Tembotrione at 0.110 kg ha^{-1}	1.90(3)c	1.52(1)b	1.00(0)a	1.90(3)b	1.46(1)b	1.00(0)a	11.59(133)d	10.29(105)c	7.37(53)b	11.82(139)d	10.42(107)c	7.37(53)b
Tembotrione at 0.088 kg ha^{-1}	1.90(3)c	1.52(1)b	1.00(0)a	1.90(3)b	1.52(1)b	1.00(0)a	11.61(134)d	10.18(103)c	7.39(54)b	11.84(140)d	10.31(105)c	7.39(54)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	9.91(97)h	5.31(27)g	3.10(9)d	7.37(53)g	4.18(17)f	1.90(3)b	20.62(425)h	17.65(311)g	13.43(179)e	24.01(575)i	18.86(355)h	13.84(191)e

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- Means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds



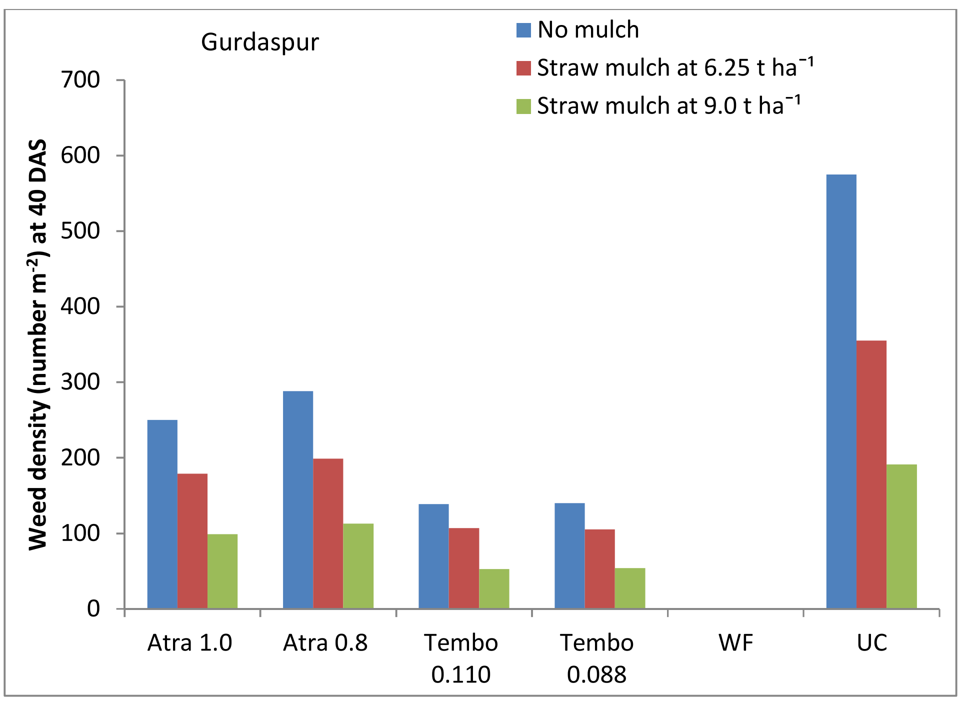


Fig. 4.1 Effect of straw mulch and weed control treatments on weed density at 40 DAS at Ludhiana and Gurdaspur

Under no mulch treatments, atrazine at lower dose (0.8 kg ha^{-1}) gave comparatively more density of grasses, broadleaf weeds and sedges than atrazine at higher dose (1.0 kg ha^{-1}). Tembotrione at lower dose (0.088 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch recorded significantly lower density of total weeds than tembotrione at 0.110 kg ha^{-1} in combination with no mulch, which indicates the beneficial effect of mulch. Thus, the results showed that 20 % herbicide dose both in atrazine and tembotrione can be reduced with application of 9.0 t ha^{-1} mulch for controlling total weeds in maize. Pandey *et al* (2002) reported that grass weeds offered maximum competition for crop growth and yield followed by broadleaf weeds and sedges.

4.1.2 Species wise weed density at harvest

At harvest, species wise density of different weeds recorded at Ludhiana and Gurdaspur are presented in table 4.12 and 4.13. The weed species observed at Ludhiana were *D. aegyptium, E. indica, C. benghalensis, E. tenella, D. sanguinalis* and *E. colona* among grasses, *D. arvensis* as broadleaf weed and *C. rotundus* and *C. compressus* were recorded as sedges whereas at Gurdaspur, *D. aegyptium, E. indica, C. dactylon* and *E. tenella* were the major grass weed species, *E. hirta, A.viridis, V. agrestis* and *C. stricta* were among broadleaf weeds and only *C. rotundus* was recorded as sedges. Similar findings with respect to change in weed flora at different locations were reported by Singh *et al* (1998) and Rout and Satapathy (1996).

The data showed that the density of different weed species at harvest was significantly affected by different straw mulch treatments at both the locations. At Ludhiana, application of 9.0 t ha^{-1} mulch resulted in significantly less density of *D. aegyptium, C. benghalensis, E. tenella, D. sanguinalis, D. arvensis* and *C. rotundus* as compared to 6.25 t ha^{-1} and no mulch treatments. However, both 6.25 and 9.0 t ha^{-1} mulch treatments recorded statistically similar and significantly lower density of *E. indica, E. colona* and *C. compressus* as compared to no mulch treatment. On the other hand at Gurdaspur, application of 9.0 t ha^{-1} mulch resulted in minimum density of *D. aegyptium, C. dactylon, A. viridis, V.agrestis* and *C. rotundus* as compared to 6.25 t ha^{-1} and no mulch treatments. Similarly, both 6.25 t ha^{-1} and 9.0 t ha^{-1} mulch treatments were statistically similar and significantly better in controlling the density of *E. indica, E. tenella, E. hirta* and *C. stricta* as compared to no mulch treatment. This showed the positive effect of straw mulch for controlling different weed species in maize as compared to no mulch treatment. Similarly Kumar *et al* (2015) also reported that mulch is a good agronomic manipulation for weed management in maize. Uwah and Iwo (2011) also observed that straw mulch resulted in significantly less weed density as compared to no mulch.

Different weed control treatments significantly affected the species-wise density at both the locations at harvest (Table 4.12 and 4.13). Minimum density of all the weed species was recorded under weed free treatment whereas maximum density was observed under unweeded check at both the locations. Among the herbicide treatments, application of tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) gave significantly better control of *D. aegyptium, C. benghalensis, E. tenella, D. arvensis* and *C. rotundus* at Ludhiana and *D. aegyptium, E. hirta, V. agrestis, C. stricta* and *C. rotundus* at Gurdaspur in comparison to atrazine at both doses (0.8 and 1.0 kg ha^{-1}). Later two treatments also recorded significantly better control of all the weed species as compared to unweeded check. Similarly, application of tembotrione at both doses and atrazine at higher dose were statistically similar in reducing the density of *E. indica, E. tenella, D. sanguinalis, E. colona* and *C. compressus* at Ludhiana and *E. indica, C. dactylon, E. tenella* and *A. viridis* at Gurdaspur but were significantly better as compared to the unweeded check. Thus, the results indicated that tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) were more effective in controlling different weeds species at harvest followed by atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg ha^{-1}.

Total weed density at harvest

The density of grasses, broadleaf weeds and sedges was recorded at Ludhiana and Gurdaspur and is presented in table 4.14. The data showed that total weed density at harvest was significantly influenced by different straw mulch treatments. Application of paddy straw mulch at 9.0 t ha^{-1} recorded significantly lowest density of grasses (8 and 6 m^{-2}), broadleaf weeds (0 and 3 m^{-2}) and sedges (3 and 13 m^{-2}) at Ludhiana and Gurdaspur, respectively as compared to 6.25 t ha^{-1} and no mulch treatments. At both the locations, application of 6.25 t ha^{-1} mulch also recorded significantly less density of grasses (13 and 11 m^{-2}), broadleaf weeds (0.6 and 7 m^{-2}) and sedges (5 and 19 m^{-2}) than no mulch treatment. Highest density of grasses (26 and 21 m^{-2}), broadleaf weeds (1 and 17 m^{-2}) and sedges (12 and 26 m^{-2}) was recorded under no mulch treatment at both the locations. Thus, the above findings indicate the benefit of straw mulch over no mulch in terms of managing the total weed density in maize. Sarwar *et al* (2013) also observed that mulch plays an important role in suppressing weeds growth.

Weed control treatments significantly influenced the total weed density at harvest (Table 4.14). Weed free treatment recorded minimum total weed density, whereas maximum density was observed under unweeded check at both the locations. Among herbicide treatments, tembotrione at 0.110 kg ha^{-1} recorded minimum total weed density which was statistically at par with tembotrione at 0.088 kg ha^{-1} but significantly more than atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg ha^{-1}. Similarly, application of tembotrione 0.088 kg ha^{-1} and tembotrione 0.110 kg ha^{-1} effectively controlled the density of total weeds (8 & 19 m^{-2} and 8 & 18 m^{-2}, respectively at Ludhiana and Gurdaspur) in comparison to atrazine 1.0 kg ha^{-1} (19 and 40 m^{-2}), atrazine 0.8 kg ha^{-1} (34 and 60 m^{-2}) and unweeded check (65 and 104 m^{-2}). Therefore, tembotrione at 0.088 kg ha^{-1} proved more beneficial than other herbicide

Table 4.12 Effect of straw mulch and weed control treatments on species-wise weed density in maize at harvest (Ludhiana)

Treatment	Weed density (number m^{-2})								
	Grasses						BLWs*	Sedges	
	D. aegyptium	*E. indica*	*C. benghalensis*	*E. tenella*	*D. sanguinalis*	*E. colona*	*D. arvensis*	*C. rotundus*	*C. compressus*
Straw mulch									
No mulch	2.60(8)c	1.24(0.7)b	2.88(9)c	2.20(5)c	1.40(2)c	1.25(0.9)b	1.46(1)c	3.04(11)c	1.33(1)b
PSM 6.25 t ha^{-1}	2.18(5)b	1.08(0.2)a	2.39(5)b	1.65(2)b	1.09(0.2)b	1.00(0)a	1.24(0.6)b	2.16(5)b	1.00(0)a
PSM 9.0 t ha^{-1}	1.81(3)a	1.00(0)a	1.90(3)a	1.40(1)a	1.00(0)a	1.00(0)a	1.00(0)a	1.76(3)a	1.00(0)a
Weed control									
Atrazine at 1.0 kg ha^{-1}	2.64(6)b	1.00(0)a	2.53(6)c	1.56(2)a	1.00(0)a	1.00(0)a	1.23(0.6)b	2.24(4)c	1.00(0)a
Atrazine at 0.8 kg ha^{-1}	3.21(10)c	1.73(0.4)b	3.08(9)d	2.16(6)b	1.00(0)a	1.00(0)a	1.38(1)c	2.97(8)d	1.00(0)a
Tembotrione at 0.110 kg ha^{-1}	1.31(0.9)a	1.00(0)a	2.14(4)b	1.27(0.7)a	1.00(0)a	1.00(0)a	1.05(0.1)a	1.77(2)b	1.00(0)a
Tembotrione at 0.088 kg ha^{-1}	1.29(0.9)a	1.00(0)a	2..06(4)b	1.27(0.7)a	1.00(0)a	1.00(0)a	1.05(0.1)a	1.65(2)b	1.00(0)a
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	3.74(13)d	1.46(1)c	3.53(12)e	2.84(8)c	1.98(4)b	1.50(2)b	1.70(2)d	4.31(20)e	1.67(3)b

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letters do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.13 Effect of straw mulch and weed control treatments on species wise weed density in maize at harvest (Gurdaspur)

Treatment	Weed density (number m^{-2})								
	Grasses				BLWs*				Sedges
	D. aegyptium	*E. indica*	*C. dactylon*	*E. tenella*	*E. hirta*	*A. viridis*	*V. agrestis*	*C. stricta*	*C. rotundus*
Straw mulch									
No mulch	1.96(3)c	1.66(2)b	1.91(3)c	1.99(4)b	1.68(2)b	1.38(1)c	2.56(7)c	1.69(2)b	4.75(26)c
PSM 6.25 t ha^{-1}	1.81(3)b	1.21(0.6)a	1.55(2)b	1.35(1)a	1.38(1)a	1.09(0.2)b	1.89(3)b	1.37(1)a	4.13(19)b
PSM 9.0 t ha^{-1}	1.27(0.9)a	1.19(0.6)a	1.27(0.8)a	1.24(0.8)a	1.30(0.8)a	1.00(0)a	1.45(1)a	1.32(0.9)a	3.34(13)a
Weed control									
Atrazine at 1.0 kg ha^{-1}	1.71(2)c	1.25(0.7)a	1.51(2)b	1.22(0.7)a	1.48(1)b	1.00(0)a	2.36(5)b	1.61(2)b	4.94(24)c
Atrazine at 0.8 kg ha^{-1}	1.80(3)c	1.40(1.3)b	1.77(2)c	1.86(3)b	1.65(2)b	1.17(0.4)b	2.67(7)b	1.97(3)c	5.50(30)d
Tembotrione at 0.110 kg ha^{-1}	1.47(1)b	1.17(0.4)a	1.38(1)b	1.17(0.4)a	1.00(0)a	1.00(0)a	1.41(1)a	1.00(0)a	3.39(11)b
Tembotrione at 0.088 kg ha^{-1}	1.54(1.6)b	1.17(0.4)a	1.41(1)b	1.22(0.7)a	1.27(0.7)a	1.00(0)a	1.13(0.4)a	1.00(0)a	3.5(11)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	2.56(6)d	2.11(4)c	2.38(5)d	2.7(8)c	2.32(5)c	1.76(3)c	3.22(11)c	2.18(4)c	6.27(39)e

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letter do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.14 Effect of straw mulch and weed control treatments on total weed density in maize at harvest

Treatment	Weed density (number m^{-2})							
	Ludhiana				Gurdaspur			
	Grasses	BLWs*	Sedges	Total	Grasses	BLWs*	Sedges	Total
Straw mulch								
No mulch	4.45(26)c	1.46(1)c	3.14(12)c	5.41(39)c	4.07(21)c	3.65(17)c	4.75(26)c	7.07(64)c
PSM 6.25 t ha^{-1}	3.41(13)b	1.24(0.6)b	2.16(5)b	3.93(19)b	3.09(11)b	2.39(7)b	4.13(19)b	5.50(37)b
PSM 9.0 t ha^{-1}	2.56(8)a	1.00(0)a	1.76(3)a	2.92(11)a	2.25(6)a	1.89(3)a	3.34(13)a	4.17(22)a
Weed control								
Atrazine at 1.0 kg ha^{-1}	3.80(14)c	1.24(0.6)c	2.24(4)c	4.36(19)c	3.17(9)c	2.71(7)c	4.94(24)c	6.34(40)c
Atrazine at 0.8 kg ha^{-1}	4.97(25)d	1.38(1)d	2.97(8)d	5.78(34)d	4.26(18)d	3.53(12)d	5.50(30)d	7.71(60)d
Tembotrione at 0.110 kg ha^{-1}	2.40(6)b	1.05(0.1)b	1.65(2)b	2.75(8)b	2.31(5)b	1.66(2)b	3.35(11)b	4.20(18)b
Tembotrione at 0.088 kg ha^{-1}	2.46(6)b	1.05(0.1)b	1.77(2)b	2.88(8)b	2.32(6)b	1.75(2)b	3.39(11)b	4.31(19)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	6.21(40)e	1.70(2)e	4.51(23)e	7.75(65)e	5.74(35)e	5.20(30)e	6.27(39)e	9.91(104)e

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in parentheses.
- In a column, means followed by same letter do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

treatments for managing the weed flora in maize. Further, atrazine at higher dose also recorded significantly less density of grasses, broadleaf and sedges as compared to its lower dose. Similarly, atrazine at lower dose also resulted in significantly less density of grasses, broadleaf and sedges as compared with unweeded check at both the locations. Mavunganidze *et al* (2014) and Arvadiya *et al* (2012) observed significantly less weed density with atrazine as pre-emergence application.

4.1.2 Dry matter accumulation of weeds

Dry matter accumulation of weeds at 20 DAS

At 20 DAS, the data on total dry matter accumulation (DMA) of weeds recorded at both the locations are presented in table 4.15. The data showed that total weed DMA was significantly influenced by straw mulch treatments which caused significant reduction in DMA of grasses, broadleaf weeds and sedges as compared to no mulch. It was observed at Ludhiana and Gurdaspur that application of 9.0 t ha^{-1} mulch recorded significantly lowest weed DMA of grasses (0.6 and 1 g m^{-2}), broadleaf weeds (0.2 and 0.2 g m^{-2}) and sedges (4 and 18 g m^{-2}) as compared to 6.25 t ha^{-1} and no mulch treatments. Similarly, application of 6.25 t ha^{-1} mulch also recorded significantly lower weed DMA of grasses, broadleaf weeds and sedges as compared to no mulch treatment. Dutta *et al* (2016) reported that straw mulch helped to reduce the weed dry matter accumulation as compared to no mulch.

Total weed DMA was also significantly affected by different weed control treatments at both the locations. The data showed that lowest DMA of weeds was recorded under weed free treatment. Among herbicides, atrazine at higher dose (1.0 kg ha^{-1}) recorded significantly less DMA of grasses, broadleaf weeds and sedges in comparison to its lower dose (0.8 kg ha^{-1}) and unweeded check at both the locations. Chopra and Angiras (2008), Woldetsadik and Chinawong (2005) and Salarzai (2001) also observed that weed DMA was effectively suppressed with atrazine over control. Similarly, atrazine at lower dose also recorded significantly less DMA of grasses, broadleaf weeds and sedges as compared to unweeded check. More DMA of weeds at 20 DAS under both doses of tembotrione was attributed to the fact that these treatments were applied after recording weed data at 20 DAS.

Dry matter accumulation of weeds at 40 DAS

Interaction between straw mulch and weed control treatments was significant with respect to total DMA of grasses, BLWs and sedges at 40 DAS at Ludhiana and Gurdaspur and are presented in table 4.16, 4.17 and fig 4.2. The data showed that application of 9.0 t ha^{-1} mulch produced significantly lower dry matter accumulation of grasses, BLWs and sedges as compared to 6.25 t ha^{-1} and no mulch treatments, irrespective of all the weed control treatments at both the locations. Similarly, application of 6.25 t ha^{-1} mulch also resulted in significantly less DMA of weeds in comparison to no mulch treatment. This showed the beneficial effect of mulch in controlling total weed biomass as compared to no

Table 4.15 Effect of straw mulch and weed control treatments on weed dry matter accumulation in maize at 20 DAS

Treatment	Weed dry matter accumulation (g m^{-2})							
	Ludhiana				Gurdaspur			
	Grasses	BLWs*	Sedges	Total	Grasses	BLWs*	Sedges	Total
Straw mulch								
No mulch	3.01(10)c	1.55(2)c	4.08(19)c	5.06(31)c	1.98(3)c	1.51(2)c	5.46(33)c	5.81(38)c
PSM 6.25 t ha^{-1}	1.40(1)b	1.21(0.5)b	2.43(6)b	2.66(8)b	1.66(2)b	1.27(0.7)b	4.49(22)b	4.72(25)b
PSM 9.0 t ha^{-1}	1.23(0.6)a	1.11(0.2)a	2.03(4)a	2.18(5)a	1.42(1)a	1.11(0.2)a	4.06(18)a	4.20(19)a
Weed control								
Atrazine at 1.0 kg ha^{-1}	1.29(0.8)b	1.07(0.1)b	1.52(2)b	1.69(3)b	1.46(1)b	1.08(0.1)b	4.72(23)b	4.84(24)b
Atrazine at 0.8 kg ha^{-1}	1.70(2)c	1.20(0.5)c	2.89(8)c	3.24(11)c	1.76(2)c	1.15(0.3)c	5.21(27)c	5.44(30)c
Tembotrione at 0.110 kg ha^{-1}	2.43(7)d	1.49(1)d	3.88(16)d	4.61(24)d	1.91(3)d	1.53(1)d	5.70(32)d	6.04(36)d
Tembotrione at 0.088 kg ha^{-1}	2.44(7)d	1.49(1)d	3.88(16)d	4.61(24)d	1.90(3)d	1.55(2)d	5.71(32)d	6.06(37)d
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	2.44(7)d	1.50(1)d	3.92(16)d	4.64(24)d	2.09(4)d	1.57(2)d	5.67(32)d	6.09(38)d

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in Parentheses.
- In a column, means followed by same letter do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.16 Interactive effect of straw mulch and weed control treatments on weed dry matter accumulation in maize at 40 DAS (Ludhiana)

Treatment	Weed dry matter accumulation (g m^{-2})											
	Grasses			BLWs*			Sedges			Total		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	7.58(57)i	3.74(13)d	3.70(11)d	2.57(6)de	2.33(5)d	1.81(2)bc	4.42(19)g	3.74(15)f	3.45(12)bc	9.03(82)g	6.19(33)e	5.51(25)d
Atrazine at 0.8 kg ha^{-1}	10.04(100)j	5.13(25)g	3.80(15)d	4.15(17)f	2.66(6)e	2.03(3)dc	6.77(45)I	4.48(19)g	3.73(15)f	12.73(162)h	7.01(50)f	6.18(33)e
Tembotrione at 0.110 kg ha^{-1}	4.53(20)ef	1.80(3)b	1.00(0)a	1.80(3)c	1.54(1)b	1.00(0)a	2.78(7)e	2.20(4)dc	1.66(1.8)b	5.53(30)d	2.91(8)c	1.66(2)b
Tembotrione at 0.088 kg ha^{-1}	4.76(22)fg	1.72(2)b	1.00(0)a	1.85(3)bc	1.53(2)b	1.00(0)a	2.92(8)e	2.20(4)dc	1.65(1.7)b	5.63(33)d	2.86(8)c	1.65(2)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	13.47(181)k	5.80(33)h	4.43(19)e	8.53(72)g	4.42(19)f	2.70(6)e	8.94(79)j	5.57(30)h	4.42(19)g	18.23(332)i	9.07(82)g	6.68(44)e

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in Parentheses.
- Means followed by same letter do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

Table 4.17 Interactive effect of straw mulch and weed control treatments on weed dry matter accumulation in maize at 40 DAS (Gurdaspur)

Treatment	Weed dry matter accumulation (g m^{-2})											
	Grasses			BLWs*			Sedges			Total		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0kg ha^{-1}	2.91(8)g	2.06(3)e	1.65(2)d	1.70(1.9)c	1.51(1.3)b	1.11(0.3)a	8.07(64)fg	6.57(44)e	4.82(23)c	8.62(74)g	6.92(49)e	5.04(25)d
Atrazine at 0.8kg ha^{-1}	3.76(13)h	2.55(6)f	2.16(4)e	2.10(3.4)d	1.89(2.6)c	1.51(1.3)b	9.18(84)h	7.61(57)f	5.58(31)d	10.05(101)h	8.19(66)f	6.02(36)e
Tembotrione at 0.110 kg ha^{-1}	1.42(1)c	1.19(0.5)b	1.00(0)a	1.03(0.1)a	1.02(0.3)a	1.00(0)a	5.04(24)d	4.16(16)c	2.99(8)b	5.14(25)d	4.22(17)c	2.99(8)b
Tembotrione at 0.088 kg ha^{-1}	1.42(1)c	1.18(0.5)b	1.00(0)a	1.14(0.4)a	1.01(0.3)a	1.00(0)a	5..07(25)d	4.09(16)c	3.08(9)b	5.18(26)d	4.14(17)c	3.08(9)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	9.12(84)i	3.68(13)h	2.89(7)g	5.62(32)f	3.17(10)e	1.83(2)c	12.74(162)i	8.53(72)gh	6.60(43)e	16.61(278)i	9.73(95)h	7.01(52)f

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in Parentheses.
- Means followed by same letter do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

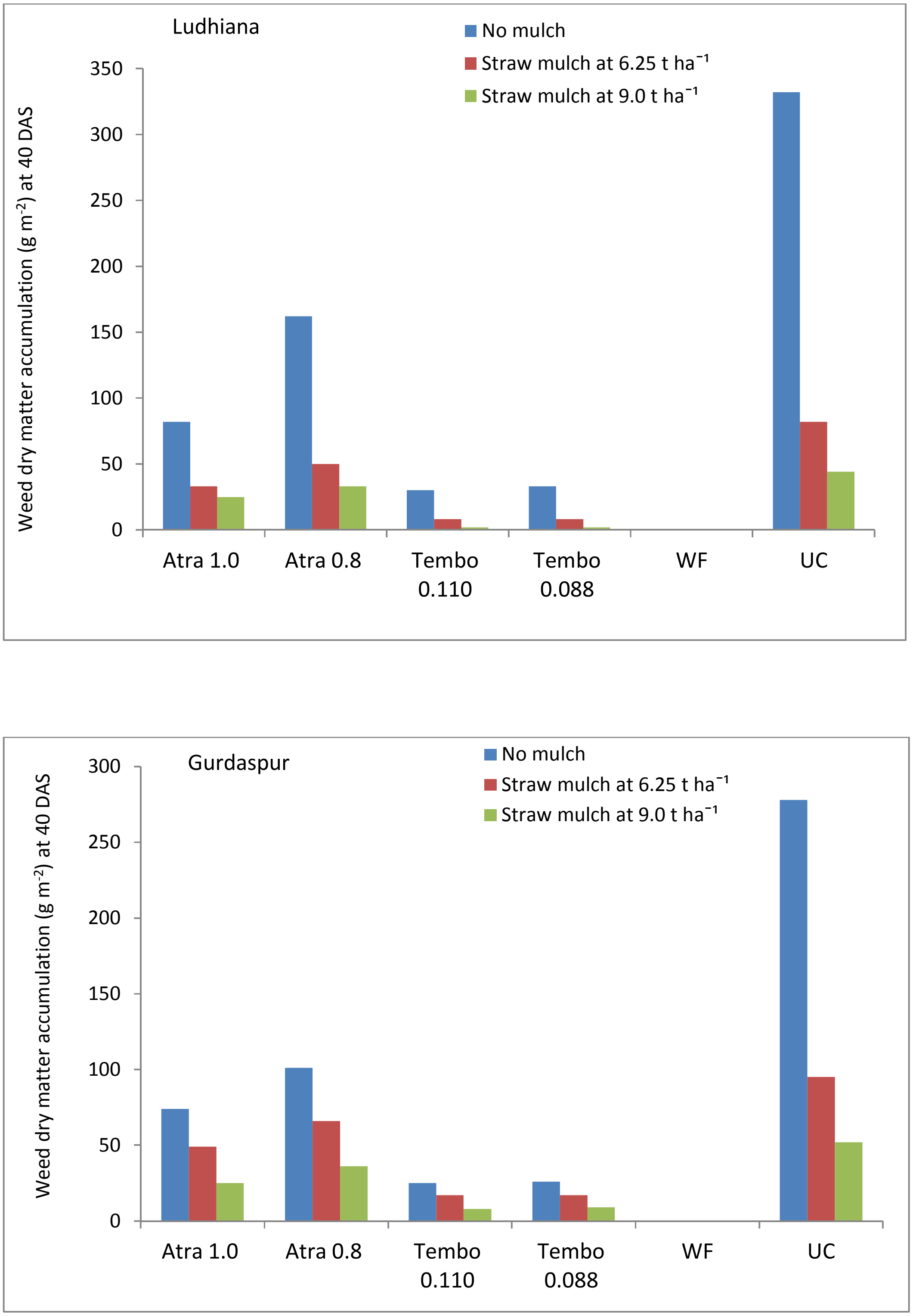


Fig. 4.2 Effect of straw mulch and weed control treatments on weed dry matter accmulation at 40 DAS at Ludhiana and Gurdaspur

mulch. Similar findings were reported by Dutta *et al* (2016) to reduce weed dry matter accumulation with straw mulch.

In case of weed control treatments, maximum total weed DMA of grasses, BLWs and sedges was recorded under unweeeded check and minimum under weed free, irrespective of straw mulch treatments. Barla *et al* (2016) also reported that weed free treatment recorded significantly less dry matter accumulation of weeds as compared to weedy check at 30 and 60 days after sowing in maize crop. Among the herbicide treatments, significantly lower total weed DMA of grasses, BLWs and sedges was obtained under tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} as compared to atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg ha^{-1} treatments, irrespective of straw mulch treatments. The data showed that tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} each in combination with 9.0 t ha^{-1} mulch recorded significantly lower DMA of total weeds as compared to all other herbicide combinations. These treatment combinations were followed by tembotrione at both doses each in combination with straw mulch at 6.25 t ha^{-1}.

Tembotrione at lower dose (0.088 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch resulted in significantly lower total weed DMA than tembotrione at 0.110 kg ha^{-1} without mulch, further tembotrione at lower dose in combination with 9.0 t ha^{-1} mulch was more effective in reducing total DMA of weeds as compared to tembotrione at 0.088 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch. Tembotrione at lower dose in combination with 6.25 t ha^{-1} mulch resulted in statistically similar DMA of grasses, BLWs and sedges as obtained under tembotrione at higher dose (0.110 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch. Atrazine at lower dose (0.8 kg ha^{-1}) in combination with paddy straw mulch at 6.25 t ha^{-1} recorded comparatively lower total weed DMA as obtained under atrazine at higher dose (1.0 kg ha^{-1}) without mulch. Above findings indicate that straw mulch helped to reduce 20% dose of tembotrione and atrazine.

Dry matter accumulation (DMA) of weeds at harvest

The data given on dry matter accumulation of grasses, broadleaf weeds and sedges at harvest were recorded at Ludhiana and Gurdaspur and are present in table 4.18. The DMA of weeds at harvest was significantly influenced by straw mulch treatments. Significantly lower dry matter accumulation of grasses (9 and 7 g m^{-2}), broadleaf weeds (0 and 2 g m^{-2}) and sedges (1 and 3 g m^{-2}) was obtained with 9.0 t ha^{-1} mulch in comparison to 6.25 t ha^{-1} and no mulch treatments at both the locations. Application of 6.25 t ha^{-1} mulch also recorded significantly lower DMA of grasses (16 and 13 g m^{-2}), broadleaf weeds (0.4 and 4 g m^{-2}) and sedges (2 and 5 g m^{-2}) than no mulch treatment. Higher dry matter accumulation of grasses (34 and 30 g m^{-2}), broadleaf (1 and 10 g m^{-2}) and sedges (5 and 8 g m^{-2}) was recorded under no mulch treatment at Ludhiana and Gurdaspur, respectively. Thus, the above findings showed the beneficial effect of straw mulch over no mulch in terms of reducing weed biomass

Table 4.18 Effect of straw mulch and weed control treatments on weed dry matter accumulation in maize at harvest

Treatment	Weed dry matter accumulation (g m^{-2})							
	Ludhiana				Gurdaspur			
	Grasses	BLWs*	Sedges	Total	Grasses	BLWs*	Sedges	Total
Straw mulch								
No mulch	5.05(34)c	1.48(1)c	2.16(5)c	5.45(40)c	4.76(30)c	2.77(10)c	2.67(8)c	7.18(48)c
PSM 6.25 t ha^{-1}	3.67(16)b	1.23(0.4)b	1.58(2)b	3.90(18)b	3.40(13)b	2.00(4)b	2.16(5)b	5.57(22)b
PSM 9.0 t ha^{-1}	2.76(9)a	1.00(0)a	1.38(1)a	2.90(10)a	2.49(7)a	1.56(2)a	1.77(3)a	4.29(12)a
Weed control								
Atrazine at 1.0 kg ha^{-1}	4.09(16)c	1.25(0.6)c	1.68(2)c	4.37(19)c	3.75(14)c	2.26(4)c	2.26(4)c	6.11(22)c
Atrazine at 0.8 kg ha^{-1}	5.19(27)d	1.37(2)d	2.05(3)d	5.57(32)d	4.70(22)d	2.92(8)d	2.83(7)d	7.59(37)d
Tembotrione at 0.110 kg ha^{-1}	2.61(6)b	1.08(0.2)b	1.30(0.7)b	2.75(7)b	2.49(6)b	1.26(0.6)b	1.55(1)b	4.07 (8)b
Tembotrione at 0.088 kg ha^{-1}	2.64(7)b	1.09(0.2)b	1.32(0.8)b	2.78(8)b	2.50(7)b	1.27(0.6)b	1.58(2)b	4.14 (10)b
Weed free	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a	1.00(0)a
Unweeded check	7.43(59)e	1.71(3)e	2.88(8)e	8.02(70)e	6.85(52)e	3.96(17)e	3.96(16)e	11.16(85)e

- Data were subjected to square root transformation $\sqrt{x+1}$. Original values are in Parentheses.
- In a column, means followed by same letter do not vary significantly at 5% level by DMRT
- BLWs*=Broad Leaf Weeds

in maize. Dutta *et al* (2016) and Chouddhary and Kumar (2014) also reported that straw mulch helped to reduce weed dry matter accumulation as compared to no mulch.

Weed control treatments also significantly influened the dry matter accumulation of all weeds at harvest at both the locations. Minimum dry matter accumulation of grasses, broadleaf, sedges and total weeds was recorded in weed free treatment, whereas maximum DMA was obtained under unweeded check. Among herbicide treatments, tembotrione at 0.088 kg ha^{-1} (8 and 10 g m^{-2}) and tembotrione at 0.110 kg ha^{-1} (7 and 8 g m^{-2}) effectively reduced total weed DMA in comparison to atrazine at 1.0 kg ha^{-1} (19 and 22 g m^{-2}), atrazine at 0.8 kg ha^{-1} (32 and 37 g m^{-2}) and unweeded check (70 and 85 g m^{-2}) at Ludhiana and Gurdaspur, respectively. Atrazine at higher dose also recorded significantly lower DMA of weeds as compared to its lower dose at both the locations. Similarly, atrazine at 0.8 kg ha^{-1} significantly lowered the biomass of weeds as compared with unweeded check. Arvadiya *et al* (2012) reported that atrazine as pre-emergence application recorded significantly less weed dry matter accumulation as compared to control. Rana *et al* (2017) also observed that the DMA of all weeds in maize was effectively reduced by tembotrione.

Weed control efficiency

Weed control efficiency was calculated and are presented in table 4.19 and fig 4.3, 4.4. At Ludhiana and Gurdaspur, application of 9.0 t ha^{-1} mulch resulted in highest weed control efficiency (95.8 and 93.9 %) as compared to 6.25 t ha^{-1} mulch (90.5 and 88.8 %) and no mulch (70.7 and 73.5 %) treatments. Application of 6.25 t ha^{-1} mulch also recorded higher weed control efficiency than no mulch treatment. Lowest weed control efficiency was recorded under no mulch treatment at both the locations. Similar findings were reported by Dutta *et al* (2016) for increased weed control efficiency with straw mulch as compared to no mulch.

Among the herbicide treatments, tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} resulted in higher WCE of 96.2 & 96.4 % and 96.2 & 96.3% at Ludhiana and Gurdaspur, respectively. Rana *et al* (2017) also reported maximum weed control efficiency with application of tembotrione. Comparatively less weed control efficiency (78.8 & 81.4%) was recorded in atrazine at 0.8 kg ha^{-1} in comparison to atrazine at 1.0 kg ha^{-1} (89.9 and 87.7 %) but atrazine at 0.8 kg ha^{-1} resulted in higher weed control efficiency as compared with unweeded check. Sahoo *et al* (2016) and Arvadiya *et al* (2012) observed significantly higher weed control efficiency with atrazine as pre-emergence application as compared to unweeded check.

Table 4.19 Effect of straw mulch and herbicide treatments on weed control efficiency in maize at 40 DAS

Treatment	Weed control efficiency (%)	
	Ludhiana	Gurdaspur
Straw mulch		
No mulch	70.7	73.5
PSM 6.25 t ha^{-1}	90.5	88.8
PSM 9.0 t ha^{-1}	95.8	93.9
Weed control		
Atrazine at 1.0 kg ha^{-1}	89.9	87.7
Atrazine at 0.8 kg ha^{-1}	78.8	81.4
Tembotrione at 0.110 kg ha^{-1}	96.2	96.3
Tembotrione at 0.088 kg ha^{-1}	96.2	96.4
Weed free	100.0	100.0
Unweeded check	-	-

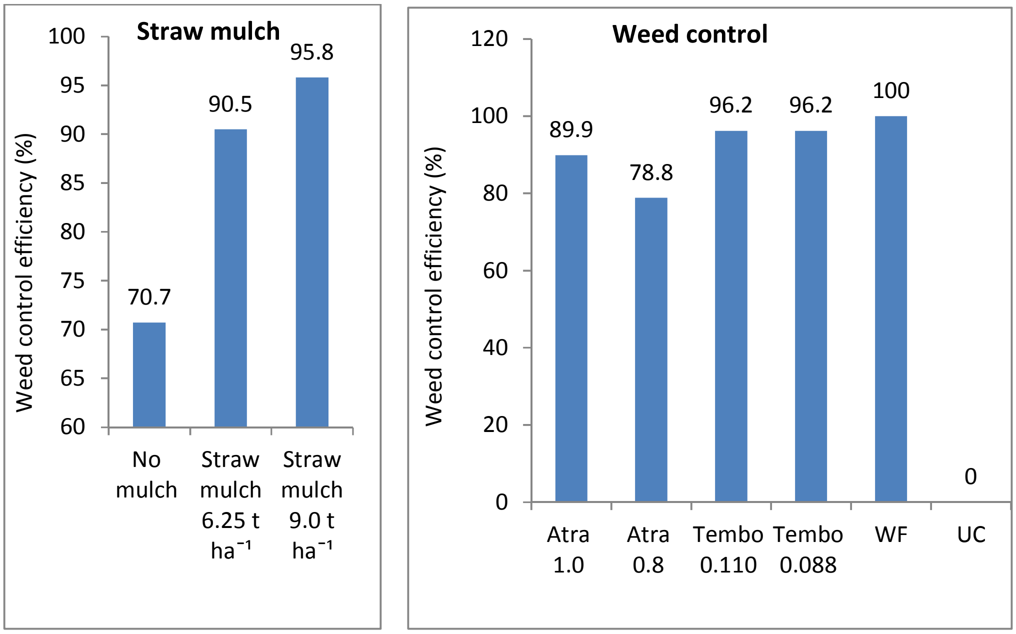


Fig. 4.3 Effect of straw mulch and weed control treatments on weed control efficiency in maize at 40 DAS (Ludhiana)

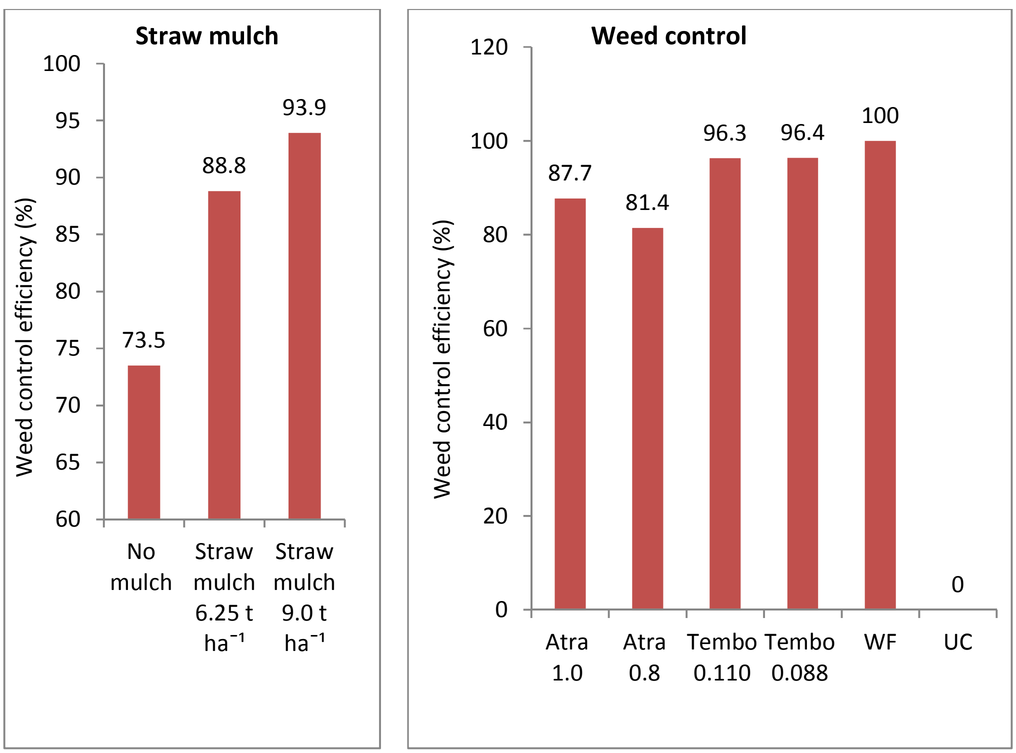


Fig. 4.4 Effect of straw mulch and weed control treatments on weed control efficiency in maize at 40 DAS (Gurdaspur)

4.2 Crop growth attributes

4.2.1 Plant stand

Plant stand was recorded at Ludhiana and Gurdaspur after 30 days of sowing and at harvest and the data are given in table 4.20. This parameter was recorded to observe the effect of different straw mulch and weed control treatments on the plant stand which may ultimately influence the grain yield of the crop. The data showed that neither different levels of straw mulch nor weed control treatments significantly influenced the plant stand both at 30 DAS and at harvest at both locations of Ludhiana and Gurdaspur.

Table 4.20 Effect of straw mulch and weed control treatments on plant stand of maize

Treatment	Plant stand (number m^{-2})			
	30 DAS		At harvest	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch				
No mulch	8.32a	8.30a	7.96a	7.99a
PSM 6.25 t ha^{-1}	8.32a	8.24a	8.09a	8.02a
PSM 9.0 t ha^{-1}	8.31a	8.30a	8.09a	8.04a
Weed control				
Atrazine at 1.0 kg ha^{-1}	8.32a	8.24a	8.11a	8.00a
Atrazine at 0.8 kg ha^{-1}	8.31a	8.30a	8.11a	7.97a
Tembotrione at 0.110 kg ha^{-1}	8.31a	8.30a	8.14a	8.04a
Tembotrione at 0.088 kg ha^{-1}	8.32a	8.30a	8.12a	8.09a
Weed free	8.33a	8.30a	8.14a	8.05a
Unweeded check	8.30a	8.24a	7.81a	7.93a

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

4.2.2 Plant height

Plant height is a genetically controlled character but it may be modified by different agronomic manipulations. Periodic plant height was recorded at 30, 60 and 90 DAS and is presented in table 4.21 and fig. 4.5, 4.6. The data showed that there was a continuously increase in plant height with the advancement of crop age at both the locations. A sharp increase was observed in plant height from 30 to 60 days after sowing, which was considered as the grand growth period of crop. Further, rate of increase was slowed down between 60 and 90 DAS. Plant height was significantly influenced by various straw mulch treatments. At 30, 60 and 90 days after sowing, maximum plant height of 66.9, 237.1 and 247.2 cm at Ludhiana and 45.0, 252.6 and 257.0 cm at Gurdaspur, respectively was

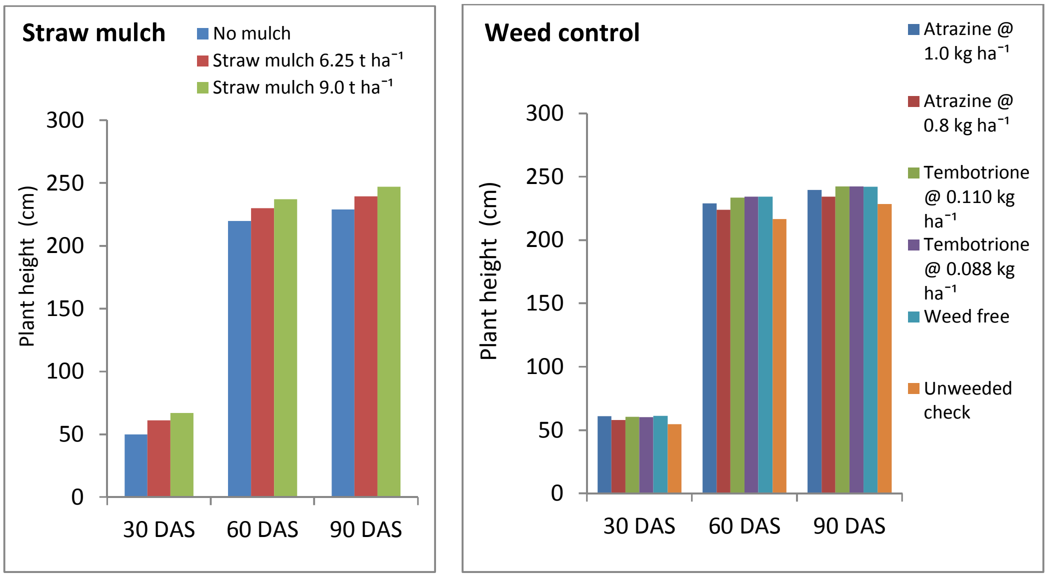


Fig 4.5 Effect of straw mulch and weed control treatments on periodic plant height of maize at Ludhiana

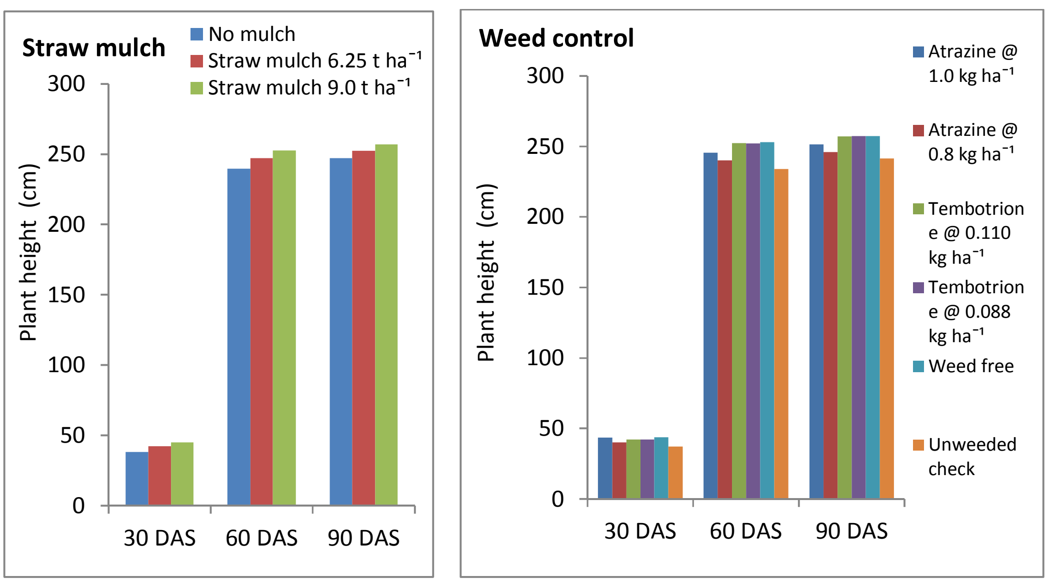


Fig 4.6 Effect of straw mulch and weed control treatments on periodic plant height of maize at Gurdaspur

observed with 9.0 t ha^{-1} mulch which was significantly higher than 6.25 t ha^{-1} and no mulch treatments. Minimum plant height of 49.9, 220.0 and 229.1 cm at Ludhiana and 38.3, 239.7 and 247.2 cm at Gurdaspur was recorded under no mulch treatment. Uwah and Iwo (2011) also reported short plant height in the unmulched treatments as compared to mulch treatments. Increase in plant height of maize under straw mulch treatments may be attributed to better conservation of soil moisture, low temperature and smothering effect on weeds (Choudhary and Kumar 2014).

The plant height of maize was significantly influenced by different weed control treatments (Table 4.21). At 30 DAS, maximum plant height of 61.2 and 43.8 cm was observed in weed free treatment at Ludhiana and Gurdaspur, respectively which was statistically at par with atrazine at 1.0 kg ha^{-1} (61.0 and 43.7 cm), tembotrione at 0.088 kg ha^{-1} (60.4 and 42.1 cm) and tembotrione at 0.110 kg ha^{-1} (60.6 and 42.2 cm), whereas, minimum plant height was recorded in unweeded check (54.7 and 37.3 cm) which was significantly less than atrazine at 0.8 kg ha^{-1} (58.1 and 40.0 cm). At 60 and 90 DAS, maximum height was recorded in tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} which was statistically at par with weed free treatment but significantly higher than atrazine at both doses and unweeded check. The improvement in plant height with weed control treatments might be attributed to the better utilization of resources due to fewer weeds that ultimately encouraged the shoot growth. Similar results were reported by Barla *et al* (2016) and Mavunganidze *et al* (2014) with atrazine as pre-emergence application. The interaction was not significant.

4.2.3 Number of leaves per plant

The number of leaves per plant at Ludhiana and Gurdaspur were recorded at 30, 60 and 90 DAS and are presented in table 4.21. There was an increase in number of leaves per plant up to 60 DAS and thereafter the increase was very small with advancement in the crop age, irrespective of the treatments. However, the maximum number of leaves per plant was recorded at 90 DAS which correspond to a period after tasselling. A perusal of data given in the table 4.21 revealed that maximum number of leaves per plant was registered with 9 t ha^{-1} mulch application which was significantly higher than no mulch treatment at 30, 60 and 90 DAS at both the locations. However, both 6.25 and 9.0 t ha^{-1} mulch treatments remained statistically at par with each other with respect to number of leaves per plant at all the growth stages. Uwah and Iwo (2011) also reported significant higher number of leaves in the mulch treatments as compared to no mulch.

The data from both locations showed that different weed control treatments significantly influenced the number of leaves per plant at all growth stages. At 30, 60 and 90 DAS, application of all herbicide treatments recorded significantly higher number of leaves per plant as compared to unweeded check. At 30 DAS, maximum number of leaves was recorded in weed free plots at both locations which were statistically at par with tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) and atrazine at 1.0 kg ha^{-1}, but significantly higher than atrazine at 0.8 kg ha^{-1} and unweeded control. However, at 60 and 90 DAS, maximum number of leaves was observed under weed free treatment which was statistically at par with tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) but was significantly higher as compared to atrazine at both doses (0.8 and 1.0 kg ha^{-1}) and unweeded check. The increase in number of leaves per plant with herbicide treatments may be attributed to increase in plant height and better crop growth. The interactive effect of straw mulch and weed control treatments was not significant with respect to number of leaves per plant.

4.2.4 Dry matter accumulation

Dry matter accumulation (DMA) is one of the most important parameters which have a marked influence on final yield realization of the crop. The optimum accumulation of dry matter followed by adequate partitioning of assimilates to the developing sinks enables the crop to attain its true yield potential. The data with respect to DMA at 30, 60 and 90 DAS are presented in table 4.22 and fig. 4.7, 4.8. The values of DMA increased continuously with the advancement of crop age and maximum values were recorded at 90 DAS. It increased at a faster rate from 30 to 60 DAS. The data showed that different straw mulch treatments had a significant influence on the dry matter accumulation at all the time intervals. At 30, 60 and 90 DAS, 9.0 t ha^{-1} mulch at both the locations resulted in significantly higher DMA in comparison to 6.25 t ha^{-1} and no mulch treatment. Application of 6.25 t ha^{-1} mulch also resulted in significantly higher DMA as compared to no mulch at all the growth stages. This may be attributed to the fact that mulch helped in controlling the weeds and changed the microclimatic conditions near plant base leading to better growth of roots and more availability of nutrients that helped the plants to maintain higher photosynthetic efficiency and significantly higher number of leaves retained per plant at 90 DAS must have contributed towards higher DMA. Kumar and Angadi (2014) also reported the beneficial effect of mulch on dry matter accumulation over no mulch.

Different weed control treatments also significantly influenced the plant dry matter accumulation at all the time intervals at Ludhiana and Gurdaspur. At 30 DAS, among the weed control treatments, maximum DMA was recorded under weed free treatment at both the locations, which was statistically at par with atrazine at 1.0 kgha^{-1} and tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) but significantly higher than atrazine at 0.8 kg ha^{-1} and unweeded check. The lowest DMA was observed under unweeded check. At 60 and 90 DAS, maximum dry matter accumulation was also recorded in weed free plots which was at par wih tembotrione at both doses but significantly higher than atrazine at both doses (0.8 and 1.0 kg ha^{-1}) and unweeded check at both the locations. This may be due to the fact that different herbicide treatments recorded significantly more WCE, higher plant height and more number of leaves per plant as compared to unweeded check that ultimately increased the DMA. The

Table 4.21 Effect of straw mulch and weed control treatments on periodic plant height and number of leaves in maize

Treatment	Plant height (cm)						Number of leaves plant^{-1}					
	30 DAS		60DAS		90DAS		30 DAS		60DAS		90DAS	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch												
No mulch	49.9c	38.3c	220.0c	239.7c	229.1c	247.2c	8.30b	6.91b	13.34b	15.12 b	13.65b	15.88b
PSM 6.25 t ha^{-1}	61.2b	42.4b	229.9b	247.1b	239.6b	252.4b	8.80a	7.20a	13.78a	15.80 a	14.17a	16.14a
PSM 9.0 t ha^{-1}	66.9a	45.0a	237.1a	252.6a	247.2a	257.0a	9.02a	7.26a	13.90a	16.03a	14.44a	16.37a
Weed control												
Atrazine at 1.0 kg ha^{-1}	61.0a	43.7a	228.9b	245.4b	239.7b	251.4b	9.07a	7.32a	13.40b	15.59b	14.00b	16.05b
Atrazine at 0.8 kg ha^{-1}	58.1b	40.0b	223.9c	240.2c	234.5c	246.0c	8.43b	6.94b	13.03c	15.24c	13.56c	15.63c
Tembotrione at 0.110 kg ha^{-1}	60.6a	42.2a	233.5a	252.4a	242.5a	257.3a	9.00a	7.19a	14.02a	15.92a	14.61a	16.43a
Tembotrione at 0.088 kg ha^{-1}	60.4a	42.1a	234.1a	252.1a	242.5a	257.5a	8.98a	7.17a	13.90a	15.91a	14.53a	16.42a
Weed free	61.2a	43.8a	234.2a	252.9a	242.2a	257.4a	9.12a	7.37a	14.00a	15.93a	14.59a	16.45a
Unweeded check	54.7c	37.3c	216.5d	233.9d	228.4d	241.5d	7.73c	6.58 c	12.59d	14.90d	13.14d	15.21d

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

Table 4.22 Effect of straw mulch and weed control treatments on periodic dry matter accumulation and leaf area index in maize

Treatment	Dry matter accumulation (g $plant^{-1}$)						Leaf area index					
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch												
No mulch	8.24c	7.11c	105.84c	126.78c	186.39c	195.50c	1.49c	1.19c	4.48c	4.69c	4.57c	4.77c
PSM 6.25 t ha^{-1}	10.90b	9.24b	123.33b	140.89b	199.83b	217.72b	1.63b	1.36b	4.85b	5.05b	4.93b	5.12b
PSM 9.0 t ha^{-1}	12.67a	11.04a	144.07a	153.33a	209.72a	241.33a	1.80a	1.53a	5.17a	5.37a	5.20a	5.43a
Weed control												
Atrazine at 1.0 kg ha^{-1}	12.13a	9.69a	128.67b	140.89b	207.67b	226.89b	1.72a	1.44a	4.87b	5.07b	4.96b	5.23b
Atrazine at 0.8 kg ha^{-1}	9.48b	8.49b	119.79c	133.78c	196.89c	216.22c	1.61b	1.30b	4.58c	4.78c	4.60c	4.80c
Tembotrione at 0.110 kg ha^{-1}	11.70a	9.46a	135.44a	148.56a	215.78a	235.89a	1.69a	1.42a	5.12a	5.34a	5.26a	5.47a
Tembotrione at 0.088 kg ha^{-1}	11.26a	9.34a	135.22a	148.78a	216.00a	235.33a	1.68a	1.40a	5.19a	5.39a	5.27a	5.44a
Weed free	12.15a	9.77a	137.70a	149.00a	218.00a	236.33a	1.76a	1.48a	5.21a	5.41a	5.29a	5.50a
Unweeded check	7.90c	7.35c	89.67d	121.00d	137.56d	154.44d	1.41c	1.13c	4.02d	4.22d	4.09d	4.30d

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

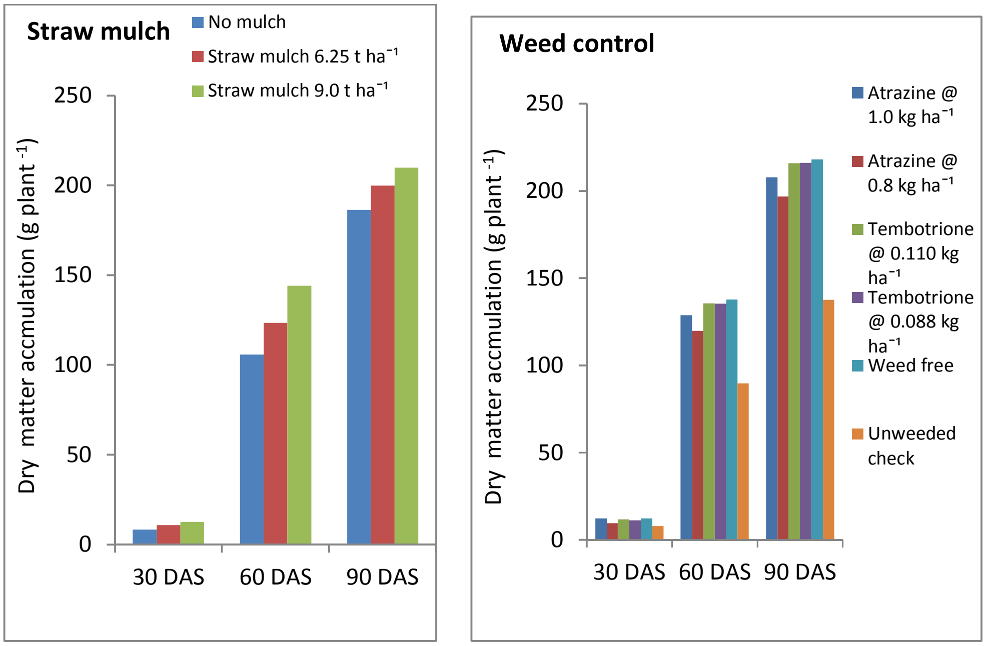


Fig 4.7 Effect of straw mulch and weed control treatments on periodic dry matter accumulation in maize at Ludhiana

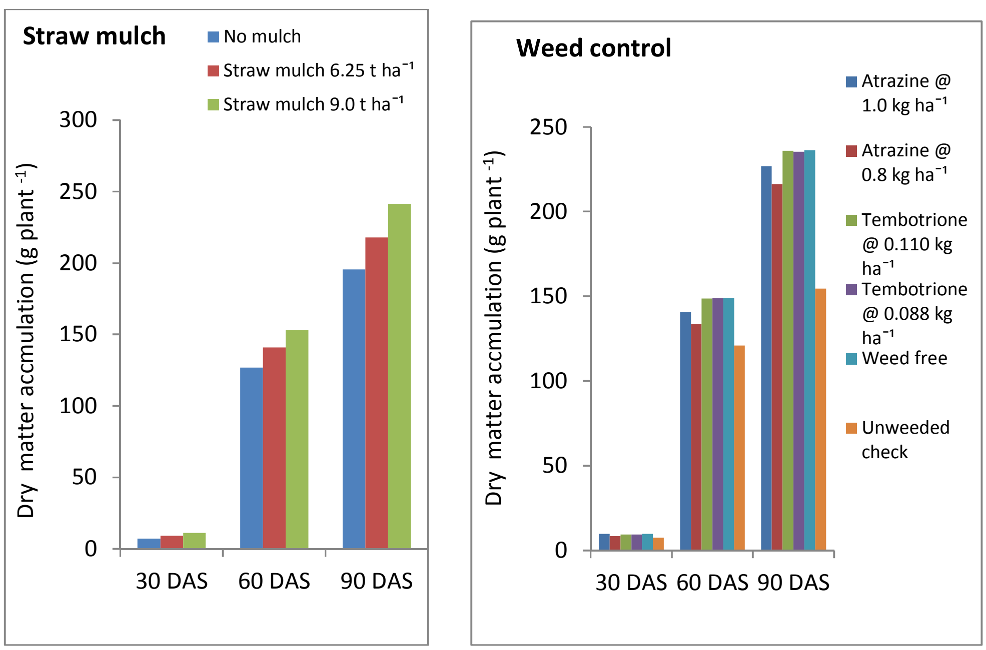


Fig 4.8 Effect of straw mulch and weed control treatments on periodic dry matter accumulation in maize at Gurdaspur

interaction was not significant.

The relationship between plant dry matter accumulation and weed dry matter accumulation was negative at harvest with respect to straw mulch and weed control treatments at both locations (Fig. 4.9 and 4.10). In case of straw mulch, the weed dry matter accumulation alone explained 92.9 to 96.9 per cent variation in plant dry matter accumulation, whereas, in case of weed control treatments, the weed dry matter accumulation alone explained 96 per cent variation in plant dry matter accumulation.

4.2.5 Leaf area index

Leaf area index is an indicator of source size. The periodic data on LAI are given in table 4.22 which revealed that LAI continue to increase sharply with the advancement of crop age up to 90 DAS, a period corresponding to the post tasselling stage and attained its maximum values at this stage at both locations of Ludhiana and Gurdaspur. The LAI was significantly influenced by straw mulch treatments at all the time intervals. Among the straw mulch treatments, maximum LAI of 1.80, 5.17 and 5.20 at Ludhiana and 1.53, 5.37 and 5.43 at Gurdaspur was recorded at 30, 60 and 90 DAS, respectively with 9.0 t ha^{-1} mulch application which was significantly higher than 6.25 t ha^{-1} and no mulch treatments. Application of 6.25 t ha^{-1} mulch also resulted in significantly higher LAI than no mulch treatment at both the locations. The higher LAI observed under 9.0 t ha^{-1} mulch treatment was due to better control of weeds and good growth of plants at initial stages as indicated by significantly taller plants (Table 4.21) and higher number of leaves per plant (Table 4.21) as compared to 6.25 t ha^{-1} and no mulch treatments.

The data given in the table 4.22 showed that different weed control treatments showed a significant effect on the LAI at 30, 60 and 90 DAS. At 30 DAS, maximum LAI of 1.76 and 1.48 was recorded under weed free treatment at Ludhiana and Gurdaspur, respectively which was statistically at par with higher dose of atrazine (1.72 and 1.44), tembotrione at 0.088 kg ha^{-1} (1.68 and 1.40) and tembotrione at 0.110 kg ha^{-1} (1.69 and 1.42) but was significantly higher than atrazine at 0.8 kg ha^{-1} (1.61 and 1.30) and unweeded check (1.41 and 1.13), later two treatments significantly differed to each other. At 60 and 90 DAS, maximum LAI was recorded under weed free treatment which was statistically at par with tembotrione at 0.088 and 0.110 kg ha^{-1} but was significantly higher than atrazine at both doses and unweeded check at both the locations. Significantly lowest LAI was observed under unweeded check. The increase in LAI with herbicide treatments might be due to higher number of leaves per plant and due to lesser leaf senescence and leaf retention for longer period. The interaction effect was not significant with respect to LAI.

4.2.6 Leaf chlorophyll content index

Higher level of chlorophyll content in leaves indicates enhanced photosynthetic efficiency of the crop which influences the crop growth and yield. The data pertaining to leaf

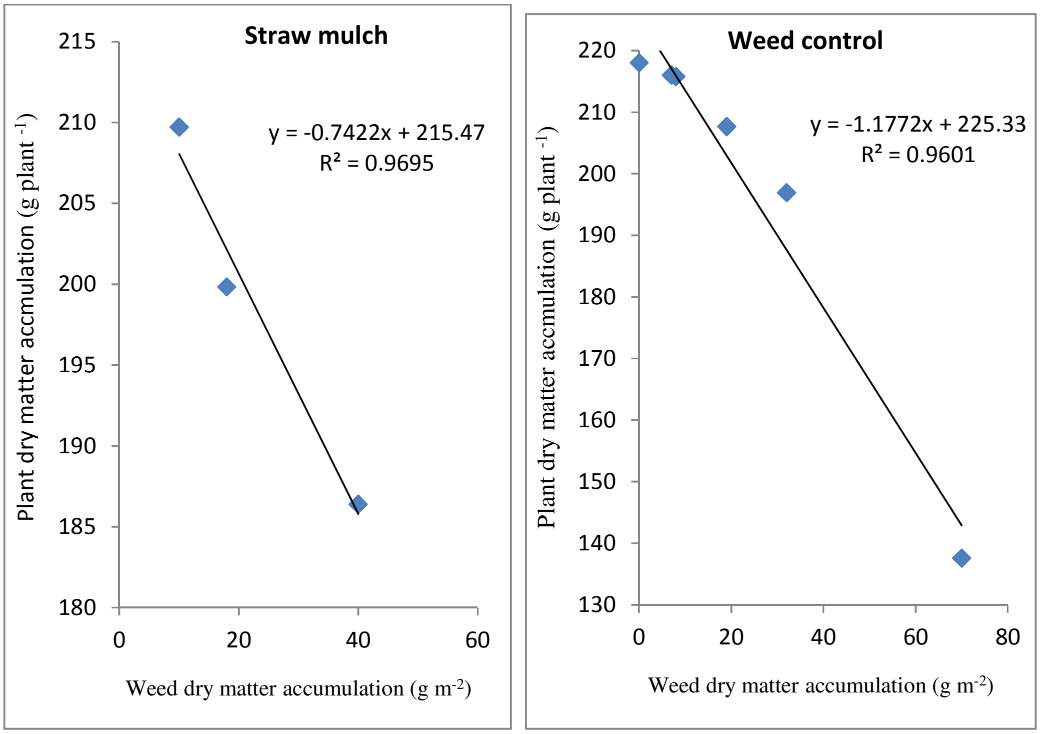


Fig. 4.9 Relationship between weed dry matter accumulation and plant dry matter accumulation at harvest in maize (Ludhiana)

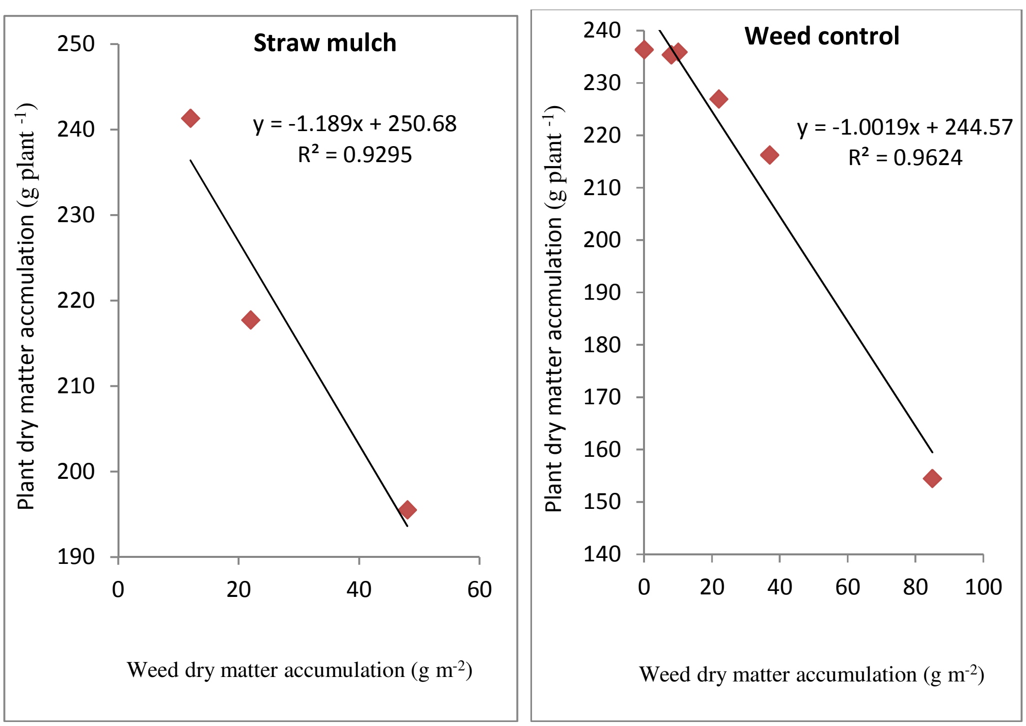


Fig. 4.10 Relationship between weed dry matter accumulation and plant dry matter accumulation at harvest in maize (Gurdaspur)

Plate 9. Recording of chlorophyll content index (SPAD values) in the experimental field

chlorophyll content in maize was recorded as Soil Plant Analysis Diagnosis (SPAD) values at 30, 40, 60 and 90 DAS and are presented in table 4.23. At all the time intervals of 30, 40, 60 and 90 DAS, application of 9.0 t ha^{-1} mulch resulted in significantly more leaf chlorophyll content index values as compared to 6.25 t ha^{-1} and no mulch treatments at both locations of Ludhiana and Gurdaspur. Similarly, 6.25 t ha^{-1} mulch also resulted in significantly higher leaf chlorophyll content index values as compared to no mulch treatment at all the time intervals. This may be attributed to the better growth of plants and more availability of nutrients under straw mulch applied treatments as compared to no mulch treatment.

Leaf chlorophyll content index values (SPAD reading) were significantly influenced by weed control treatments at both the locations. At 30 DAS, maximum leaf chlorophyll content index values of 24.34 and 25.06 were recorded under weed free treatment at Ludhiana and Gurdaspur, respectively which were statistically at par with tembotrione at 0.088 kg ha^{-1} (23.63 and 24.51), atrazine at 1.0 kg ha^{-1} (23.83 and 24.72) and tembotrione at 0.110 kg ha^{-1} (23.98 and 24.73) treatments but was significantly higher than atrazine at 0.8 kg ha^{-1} (22.85 and 23.04) and unweeded check (21.18 and 21.39), later two treatments significantly varied to each other. At 40, 60 and 90 DAS, statistically similar SPAD values were obtained under weed free and tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) treatments which were significantly higher than atrazine at both doses (0.8 and 1.0 kg ha^{-1}) and unweeded check at both the locations. However, minimum values of leaf chlorophyll content index were observed under unweeded check. The interaction effect was not significant.

4.2.7 Photosynthetically active radiation (PAR) interception

PAR interception and its distribution within the crop canopy is an important determinant of photosynthetic activities of the crop. PAR interception within the crop canopy influences the leaf photosynthesis efficiency, which in turn affects the dry matter production and grain yield. The periodic data on PAR interception recorded at 30, 40, 60 and 90 DAS are presented in table 4.24 which showed that straw mulch significantly influenced the PAR interception in maize at all the periodic time intervals.

Application of 9.0 t ha^{-1} mulch performed significantly better for PAR interception than 6.25 t ha^{-1} mulch and the later treatment also recorded significantly higher PAR interception than no mulch treatment. Maximum PAR interception of 48.73, 61.05, 77.13 and 87.32 % at Ludhiana and 47.53, 59.34, 76.65 and 85.19 % at Gurdaspur was observed with 9.0 t ha^{-1} mulch at 30, 40, 60 and 90 DAS, respectively. Significantly higher PAR interception under straw mulch treatments was due to more plant height, number of leaves and LAI as compared to no mulch treatment. Since maize leaves are not generally light saturated, more interception of PAR along with more uptake of CO_2 can increase photosynthesis which can contribute towards higher yields through more production of carbohydrates and their subsequent translocation towards sink.

Table 4.23 Effect of straw mulch and weed control treatments on leaf chlorophyll content index (SPAD values) in maize

Treatment	Leaf chlorophyll content index							
	30 DAS		40 DAS		60 DAS		90 DAS	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch								
No mulch	21.39c	22.16c	24.82c	25.15c	32.59c	30.0c	35.37c	32.88c
PSM 6.25 t ha^{-1}	23.66b	24.23b	27.72b	28.11b	34.50b	32.03b	38.93b	36.54b
PSM 9.0 t ha^{-1}	24.85a	25.33a	29.67a	30.06a	36.47a	34.09a	41.60a	39.38a
Weed control								
Atrazine at 1.0 kg ha^{-1}	23.83a	24.72a	27.57b	27.91b	35.57b	33.15b	38.94b	36.73b
Atrazine at 0.8 kg ha^{-1}	22.85b	23.04b	26.22c	26.55c	33.36c	29.94c	35.30c	33.14c
Tembotrione at 0.110 kg ha^{-1}	23.98a	24.73a	29.09a	29.38a	36.54a	34.67a	41.66a	39.95a
Tembotrione at 0.088 kg ha^{-1}	23.63a	24.51a	29.05a	29.43a	36.33a	34.74a	41.93a	39.83a
Weed free	24.34a	25.06a	29.04a	29.59a	37.07a	34.71a	42.22a	39.73a
Unweeded check	21.18c	21.39c	23.44d	23.78d	28.26d	25.05d	31.74d	28.22d

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

Table 4.24 Effect of straw mulch and weed control treatments on periodic PAR interception in maize

Treatment	PAR interception (%)							
	30 DAS		40 DAS		60 DAS		90 DAS	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch								
No mulch	44.39c	43.16c	56.33c	55.17c	72.79c	72.14c	81.88c	80.37c
PSM 6.25 t ha^{-1}	46.69b	45.37b	58.57b	57.16b	75.36b	75.03b	84.79b	83.08b
PSM 9.0 t ha^{-1}	48.73a	47.53a	61.05a	59.34a	77.13a	76.65a	87.32a	85.19a
Weed control								
Atrazine at 1.0 kg ha^{-1}	48.37a	47.41a	59.71b	58.71b	75.33b	74.93b	85.10b	83.06b
Atrazine at 0.8 kg ha^{-1}	45.20b	44.23b	57.40c	56.24c	73.38c	72.70c	83.11c	81.31c
Tembotrione at 0.110 kg ha^{-1}	48.76a	46.71a	61.24a	59.26a	77.36a	77.35a	86.93a	84.89a
Tembotrione at 0.088 kg ha^{-1}	48.27a	46.56a	61.10a	59.30a	77.84a	77.11a	87.29a	84.87a
Weed free	48.42a	47.17a	61.37a	59.70a	77.92a	77.45a	86.79a	85.16a
Unweeded check	40.61c	40.05c	51.14d	50.11d	68.82d	68.11d	78.76d	78.00d

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

Different weed control treatments significantly influenced the PAR interception in maize at all the time intervals. At 30 DAS, application of tembotrione at both doses (0.088 and 0.110 kg ha^{-1}), atrazine at higher dose (1.0 kg ha^{-1}) and weed free treatments recorded statistically similar values of PAR interception and these treatments were significantly better than atrazine at lower dose and unweeded check at both the locations. Similarly at 40, 60 and 90 DAS, application of tembotrione at 0.088 kg ha^{-1}, tembotrione at 0.110 kg ha^{-1} and weed free treatments recorded statistically similar values of PAR interception and all these treatments resulted in significantly higher values of PAR interception than atrazine at both doses and unweeded check at both the locations. Similarly, application of atrazine at 1.0 kg ha^{-1} also registered higher PAR interception than atrazine at 0.8 kg ha^{-1} and unweeded check. Significantly lower PAR interception values were observed under unweeded check at both the locations. The increase in PAR interception under these weed control treatments might be due to more plant height, number of leaves per plant, LAI and leaf chlorophyll content. The interaction was not significant.

4.2.8 Soil temperature at 5 cm depth

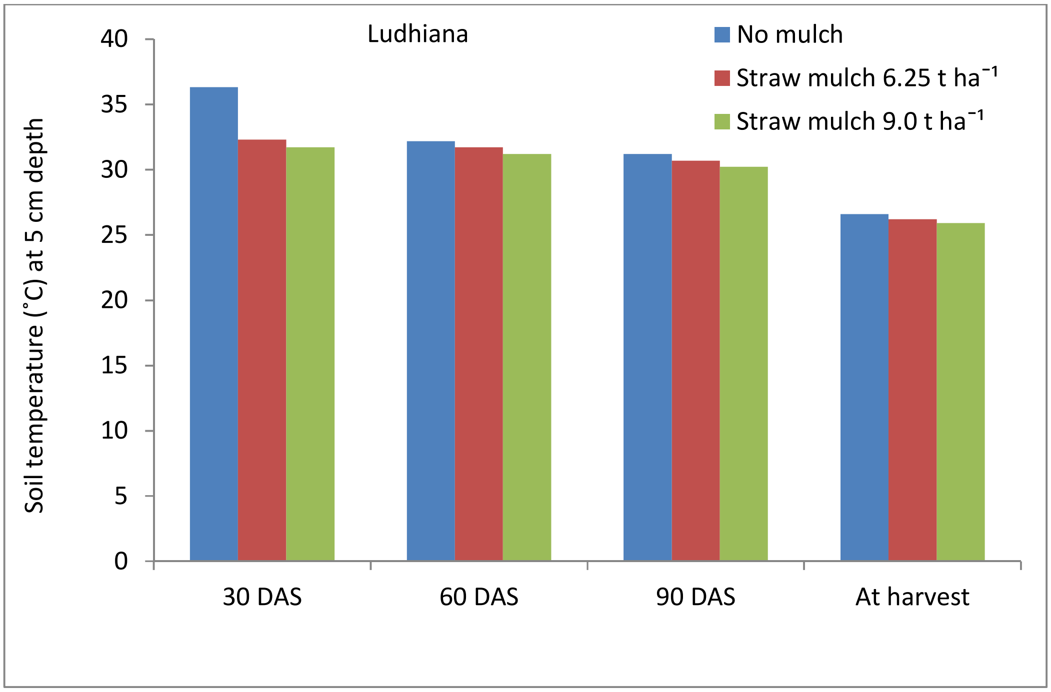
Soil temperature is an important parameter to check the effect of mulch on weed population and plant growth. The data on soil temperature recorded at 5 cm depth are presented in table 4.25 and fig 4.11. The values of soil temperature varied with time intervals and a continuous decrease in soil temperature was observed with the advancement of the crop age. The data showed that straw mulch treatments significantly influenced the soil temperature at 5 cm depth. At 20, 40, 60 DAS and at harvest, lowest values of soil temperature (31.7, 31.2, 30.2 and 25.9 ^{0}C, respectively) were observed with 9.0 t ha^{-1} mulch at Ludhiana which were significantly less than that recorded under 6.25 t ha^{-1} mulch (32.3, 31.7, 30.7 and 26.2 ^{0}C) and no mulch (36.3, 32.2, 31.2 and 26.6 ^{0}C) treatments. Later two treatments also differed significantly with respect to the soil temperature at 5 cm. Similarly at Gurdaspur, lowest values of soil temperature (30.5, 30.1, 29.1 and 28.5 ^{0}C) were observed with 9.0 t ha^{-1} mulch at 20, 40, 60 DAS and at harvest, respectively which were significantly less than that recorded under at 6.25 t ha^{-1} mulch (31.5, 30.5, 29.5 and 29.1 ^{0}C) and no mulch (34.3, 31.5, 30.4 and 29.7 ^{0}C) treatments. This showed that application of 9.0 t ha^{-1} mulch reduced the soil temperature by 4.6, 1.0, 1.0 and 0.7 ^{0}C at Ludhiana and 3.8, 1.4, 1.3 and 1.2 ^{0}C at Gurdaspur as compared to no mulch treatment at 20, 40, 60 DAS and at harvest, respectively. Similarly, 6.25 t ha^{-1} mulch also reduced the soil temperature by 4.0, 0.5, 0.5 and 0.4 ^{0}C at Ludhiana and 2.8, 1.0, 0.9 and 0.6 ^{0}C at Gurdaspur as compared to no mulch treatment at 20, 40, 60 DAS and at harvest, respectively.

Different weed control treatments did not significantly influence the soil temperature at 5 cm depth at both the locations. The interaction was not significant with respect to soil temperature at 5 cm depth.

Table 4.25 Effect of straw mulch and weed control treatments on soil temperature at 5 cm depth in maize

Treatment	Soil temperature at 5 cm depth (^{0}C)							
	20 DAS		40 DAS		60 DAS		At harvest	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch								
No mulch	36.3c	34.3c	32.2c	31.5c	31.2c	30.4c	26.6c	29.7c
PSM 6.25 t ha^{-1}	32.3b	31.5b	31.7b	30.5b	30.7b	29.5b	26.2b	29.1b
PSM 9.0 t ha^{-1}	31.7a	30.5a	31.2a	30.1a	30.2a	29.1a	25.9a	28.5a
Weed control								
Atrazine at 1.0 kg ha^{-1}	33.6a	32.3a	31.9a	30.7a	30.7a	29.6a	26.3a	29.1a
Atrazine at 0.8 kg ha^{-1}	33.2a	32.0a	31.8a	30.7a	30.6a	29.7a	26.3a	29.0a
Tembotrione at 0.110 kg ha^{-1}	33.4a	31.8a	31.8a	30.6a	30.7a	29.6a	26.4a	29.1a
Tembotrione at 0.088 kg ha^{-1}	33.6a	32.1a	31.8a	30.6a	30.7a	29.7a	26.2a	29.1a
Weed free	33.1a	32.0a	31.8a	30.7a	30.7a	29.7a	26.3a	29.2a
Unweeded check	33.5a	32.3a	31.8a	30.7a	30.7a	29.7a	26.3a	29.1a

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT



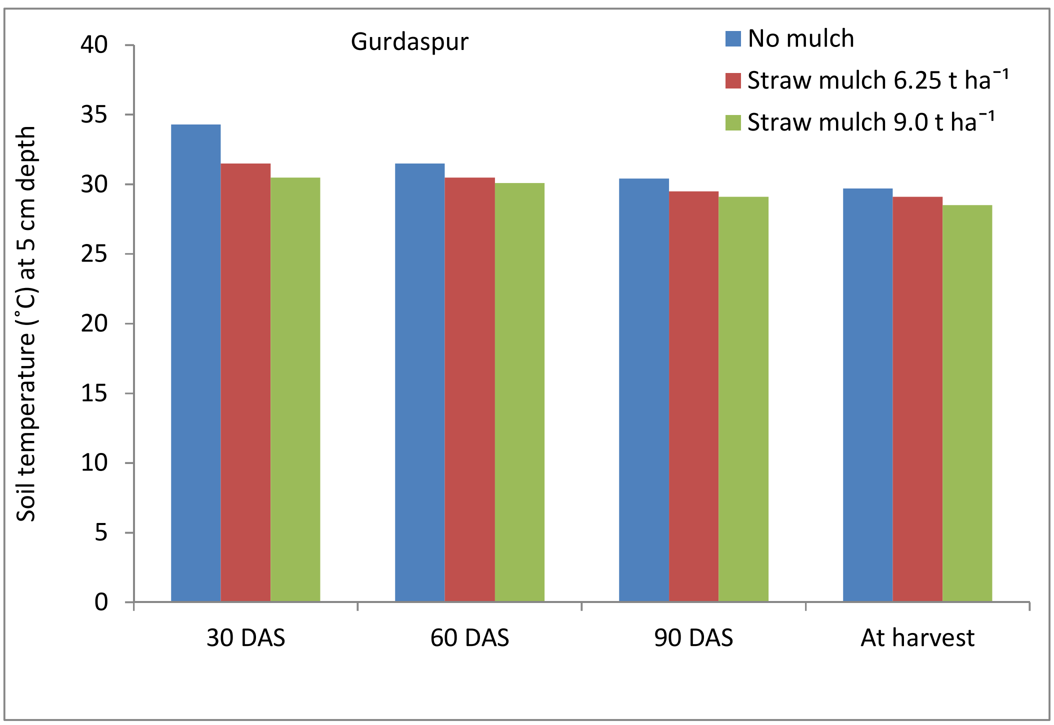


Fig. 4.11 Effect of straw mulch on soil temperature at 5 cm depth in maize at Ludhiana and Gurdaspur

4.2.9 Soil temperature at 10 cm

Soil temperature at 10 cm depth was significantly affected by the straw mulch treatments (Table 4.26, Fig. 4.12). At Ludhiana, the soil temperature was significantly reduced with application of 9.0 t ha^{-1} mulch (31.6, 30.3, 30.6 and 26.9 ^{0}C) and 6.25 t ha^{-1} (32.1, 30.7, 30.7 and 27.0 ^{0}C) as compared to no mulch (35.3, 31.6, 31.1 and 27.3 ^{0}C) treatment at 20, 40, 60 DAS and at harvest, respectively. However at 20 and 40 DAS, 9.0 t ha^{-1} mulch recorded significantly lower temperature as compared to 6.25 t ha^{-1} mulch but both above treatments remained on par with each other at 60 DAS and at harvest with respect to the soil temperature at both the locations. Same trend was observed at Gurdaspur where statistically similar soil temperature values of 30.5, 29.6, 29.6, 27.7 and 30.9, 30.3, 29.8 and 27.8 ^{0}C were observed with the application of 9.0 and 6.25 t ha^{-1} mulch at 20, 40, 60 DAS and at harvest, respectively which were significantly less than that recorded under no mulch (32.7, 30.9, 30.1 and 28.1 ^{0}C) treatment. This showed that application of 9.0 t ha^{-1} mulch at 20, 40, 60 DAS and at harvest reduced the soil temperature by 3.7, 1.3, 0.5 and 0.4 ^{0}C at Ludhiana and 2.2, 1.3, 0.5 and 0.4 ^{0}C, respectively at Gurdaspur as compared to no mulch treatment. Similarly, 6.25 t ha^{-1} mulch also reduced the soil temperature by 3.2, 0.9, 0.4 and 0.3 ^{0}C at Ludhiana and 1.8, 0.6, 0.3 and 0.3 ^{0}C at Gurdaspur as compared to no mulch treatment at 20, 40, 60 DAS and at harvest, respectively.

Different weed control treatments did not significantly influenced the soil temperature values at 10 cm depth at both the locations. The interaction was not significant with respect to soil temperature at 10 cm depth.

4.3 Crop phenology

4.3.1 Days taken to 50 per cent emergence

The data presented in table 4.27 showed that application of different straw mulch and weed control treatments did not significantly affect the days taken to emergence, thus indicating that crop took almost equal number of days (5.8 to 5.9 days at Ludhiana and 6.2 to 6.9 days at Gurdaspur) to emerge under different treatments. The interaction was also not significant.

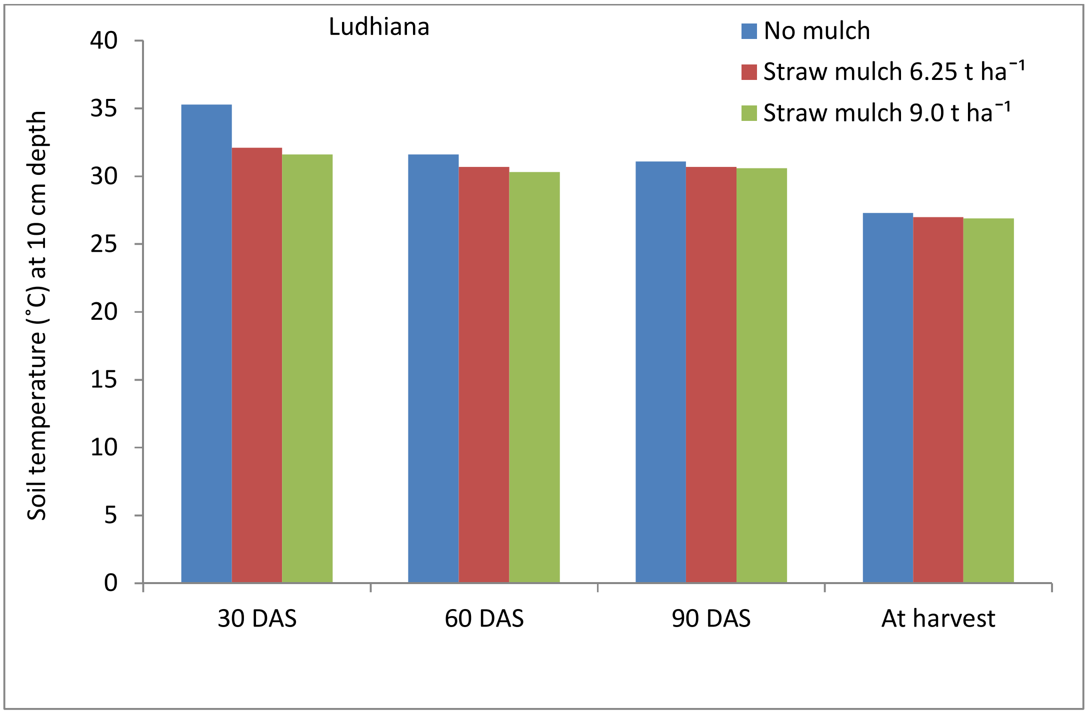
4.3.2 Days taken to 50 per cent tasselling

A perusal of the data given in table 4.27 revealed that various straw mulch treatments significantly influenced the number of days taken to 50 per cent tasselling stage. At Ludhiana and Gurdaspur, both paddy straw mulch treatments at 9.0 and 6.25 t ha^{-1} took significantly less number of days to tasselling (53.1 & 59.3 days and 53.3 & 60.1 days) as compared to no mulch treatment (55.5 and 61.1 days). This showed that tasselling stage was enhanced by 2.2 to 2.4 days at Ludhiana and 1.0 to 1.8 days at Gurdaspur under both straw mulch treatments as compared to without mulch. This may be attributed to better plant growth under these straw mulch treatments as evident from more plant height, leaves per plant and DMA.

Table 4.26 Effect of straw mulch and weed control treatments on soil temperature at 10 cm depth in maize

Treatment	Soil temperature at 10 cm depth (^{0}C)							
	20 DAS		40 DAS		60 DAS		At harvest	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch								
No mulch	35.3c	32.7c	31.6c	30.9c	31.1b	30.1b	27.3b	28.1b
PSM 6.25 t ha^{-1}	32.1b	30.9b	30.7b	30.3b	30.7a	29.8a	27.0a	27.8a
PSM 9.0 t ha^{-1}	31.6a	30.5a	30.3a	29.6a	30.6a	29.6a	26.9a	27.7a
Weed control								
Atrazine at 1.0 kg ha^{-1}	33.0a	31.4a	30.9a	30.3a	30.9a	29.9a	27.2a	27.8a
Atrazine at 0.8 kg ha^{-1}	32.9a	31.4a	30.8a	30.3a	30.8a	29.9a	27.1a	27.8a
Tembotrione at 0.110 kg ha^{-1}	33.1a	31.1a	30.8a	30.2a	30.7a	29.9a	27.2a	27.9a
Tembotrione at 0.088 kg ha^{-1}	33.1a	31.2a	30.8a	30.3a	30.8a	30.0a	27.0a	27.9a
Weed free	32.9a	31.3a	30.9a	30.2a	30.8a	29.9a	27.0a	27.9a
Unweeded check	33.0a	31.6a	31.0a	30.3a	30.7a	29.9a	27.1a	27.9a

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT



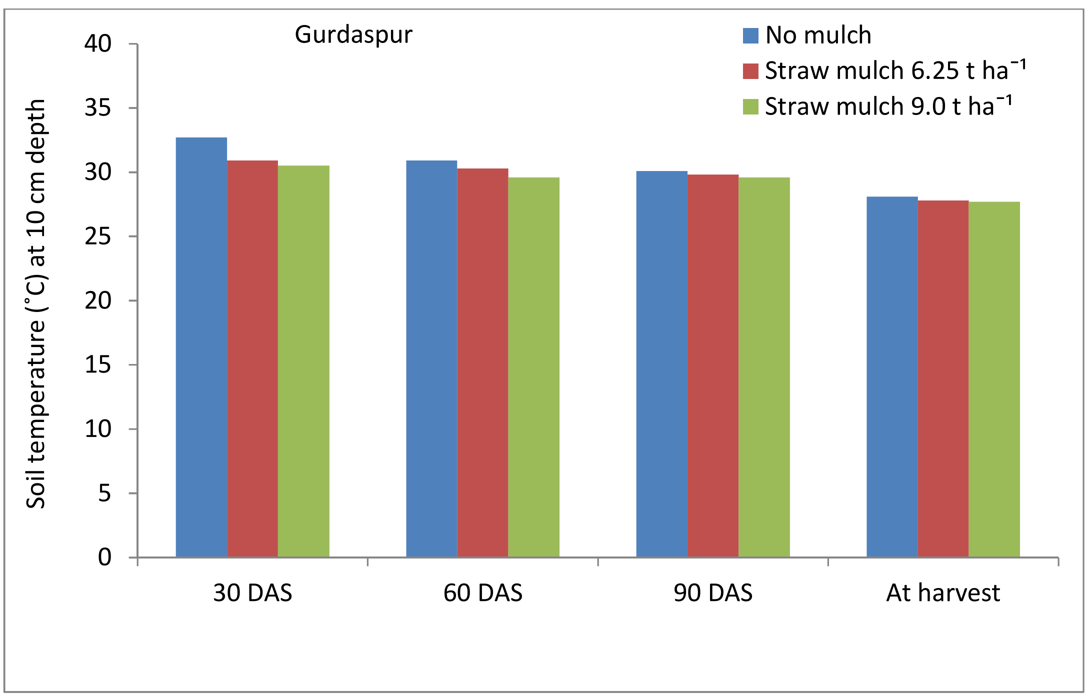


Fig. 4.12 Effect of straw mulch on soil temperature at 10 cm depth in maize at Ludhiana and Gurdaspur

The data showed that different weed control treatments showed a significant influenced on days taken to tasselling at both the locations. At Ludhiana and Gurdaspur, weed free, tembotrione at both doses (0.110 & 0.088 kg ha^{-1}) and atrazine at higher dose (1.0 kg ha^{-1}) took significantly less number of days to tasselling in comparison to atrazine at lower dose and unweeded check. Reduction in number of days taken for tasselling stage under different weed control treatments may be attributed to better plant growth resulting in increased energy levels in plants which enhanced the tasselling stage. The interaction was not significant.

4.3.2 Days taken to 50 per cent silking

Likewise the days taken to 50 per cent tasselling, the number of days taken to 50 per cent silking stage was also significantly affected by different straw mulch treatments (Table 4.27). At Ludhiana and Gurdaspur, significantly less number of days to silking were taken with 9.0 t ha^{-1} mulch (58.1 and 63.8 days) and 6.25 t ha^{-1} mulch (58.4 and 64.4 days) as compared to no mulch (59.8 & 65.4 days) treatment. This showed that silking stage was enhanced by 1.4 to 1.7 days at Ludhiana and 1.0 to 1.6 days at Gurdaspur under both mulch treatments as compared to no mulch treatment. This may be attributed to better plant growth under these straw mulch treatments.

Different weed control treatments showed significant effect on number of days taken to silking stage. Tembotrione at both doses (0.110 & 0.088 kg ha^{-1}), atrazine at both doses (1.0 & 0.8 kg ha^{-1}) and weed free treatments took lowest number of days for silking stage as compared to unweeded check at both locations. Reduction in number of days taken for silking with different weed control treatments may be attributed to better plant growth resulting in increased energy levels in plants which enhanced the silking stage. The interaction effect was not significant.

4.3.4 Days taken to physiological maturity

The data on the number of days taken to reach 50 per cent physiological maturity are presented in table 4.27. At Ludhiana and Gurdaspur, significantly less number of days to physiological maturity were taken by the crop with 9.0 t ha^{-1} mulch (93.2 and 95.7 days) and 6.25 t ha^{-1} mulch (93.2 and 96.1 days) as compared to no mulch (93.8 and 96.8 days) treatment. This showed that physiological maturity was enhanced by 0.6 to 0.8 days at Ludhiana and 0.7 to 1.1 days at Gurdaspur under both the mulch treatments as compared to without mulch treatment. Enhanced physiological maturity may be attributed to better plant growth under these straw mulch applied treatments.

Different weed control treatments significantly influenced the number of days taken to 50 per cent physiological maturity. At Ludhiana and Gurdaspur, tembotrione at both doses, atrazine at both doses and weed free treatments took lowest number of days for physiological maturity as compared to unweeded check. Reduction in number of days taken for

Table 4.27 Effect of straw mulch and weed control treatments on number of days taken to different phenological growth stages in maize

Treatment	Phenological growth stages							
	50 per cent emergence		50 per cent tasselling		50 per cent silking		Physiological maturity	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch								
No mulch	5.9a	6.8a	55.5b	61.1b	59.8b	65.4b	93.8b	96.8b
PSM 6.25 t ha^{-1}	5.8a	6.6a	53.3a	60.1a	58.4a	64.4a	93.2a	96.1a
PSM 9.0 t ha^{-1}	5.8a	6.6a	53.1a	59.3a	58.1a	63.8a	93.2a	95.7a
Weed control								
Atrazine at 1.0 kg ha^{-1}	5.9a	6.2a	53.8a	60.3a	58.7a	64.6a	93.0a	96.2a
Atrazine at 0.8 kg ha^{-1}	5.9a	6.8a	54.3b	61.5b	58.8a	65.4a	93.2a	96.4a
Tembotrione at 0.110 kg ha^{-1}	5.8a	6.8a	53.6a	59.3a	58.6a	63.4a	93.0a	95.9a
Tembotrione at 0.088 kg ha^{-1}	5.9a	6.7a	53.6a	59.2a	58.4a	63.4a	92.9a	95.9a
Weed free	5.8a	6.7a	53.4a	59.4a	58.4a	63.6a	92.9a	95.9a
Unweeded check	5.9a	6.9a	55.4b	61.7b	59.7b	66.6b	94.6b	97.2b

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

physiological maturity under different weed control treatments may be attributed to better plant growth and less infestation by weeds which enhanced the physiological maturity stage in maize. The interaction effect due to various treatments was not significant.

4.4 Yield contributing attributes and yield

4.4.1 Number of cobs per plant

The data regarding the number of cobs per plant are presented in table 4.28 which revealed that straw mulch and weed control treatments did not significantly influence the number of cobs per plant. However, both 9.0 t ha^{-1} and 6.25 t ha^{-1} mulch application produced numerically higher number of cobs per plant (1.11 & 1.03 and 1.06 & 1.02) as compared to no mulch treatment (1.00 and 1.01) at Ludhiana and Gurdaspur. Similarly weed free, tembotrione at both doses also recorded numerically more number of cobs per plant than atrazine at both doses and unweeded check at both the locations. The interaction effect was not significant.

4.4.2 Cob length

To some extent, cob length is related to the number of grains per row and affects the total number of grains per cob and grain yield. The data on cob length was presented in table 4.28. It showed that maximum cob length (18.11 and 18.72 cm) was observed with the 9.0 t ha^{-1} mulch which was significantly higher than 6.25 t ha^{-1} and no mulch treatments. Lowest cob length was recorded under no mulch treatment at both the locations. Kumar and Angadi (2014) reported the beneficial effect of mulch on yield attributes over no mulch.

The cob length was significantly influenced by different weed control treatments. Maximum cob length of 18.34 and 18.31 cm was recorded under weed free treatment at Ludhiana and Gurdaspur, respectively which was statistically at par with tembotrione at both doses but significantly higher than atrazine at both doses and unweeded check. Significantly lowest cob length of 16.40 and 15.98 cm at both the locations was observed under unweeded check. The interaction effect was not significant.

4.4.3 Cob girth

Cob girth is an indication of total number of rows per cob and ultimately the total number of grains per cob. The data on cob girth are presented in table 4.28. Application of straw mulch significantly influenced the cob girth at both the locations. The data revealed that application of 9.0 t ha^{-1} mulch resulted in significantly higher cob girth as compared to 6.25 t ha^{-1} and no mulch treatments. Application of 6.25 t ha^{-1} mulch also recorded significantly higher cob girth than no mulch treatment at both the locations. Similar findings were reported by Kumar and Angadi (2014).

Among weed control treatments, tembotrione at both doses and weed free treatments recorded statistically similar cob girth and these treatments were significantly better than atrazine at both doses and unweeded check. Significantly lower cob girth was observed under unweeded check at both the locations. The interaction was not significant with respect to the cob girth.

4.4.4 Number of rows per cob

The number of rows per cob has a direct effect on number of grains per cob. The data given on number of rows per cob in table 4.28 indicated that application of 9.0 t ha^{-1} mulch resulted in significantly higher number of rows per cob as compared 6.25 t ha^{-1} and no mulch treatments. Application of 6.25 t ha^{-1} mulch also recorded significantly higher number of rows per cob than no mulch treatment at both the locations.

The number of rows per cob was significantly influenced by different weed control treatments. At both the locations, maximum number of rows per cob was observed with the application of tembotrione at higher dose which was statistically at par with tembotrione at lower dose and weed free treatments but was significantly higher than atrazine at both doses and unweeded check. Minimum number of rows per cob was observed under unweeded check. Similar results were reported by Barla *et al* (2016) and Gul *et al* (2016) with atrazine as pre-emergence application.

The interaction was significant with respect to number of rows per cob (Table 4.29). The data showed that at Ludhiana and Gurdaspur, maximum number of rows per cob (14.9 and 14.9) were recorded with tembotrione at 0.088 kg ha^{-1} in combination with paddy straw mulch at 9.0 t ha^{-1} which was statistically at par with tembotrione at 0.110 kg ha^{-1} (14.8 and 14.8) and weed free (14.9 and 14.8) each in combination with 9.0 t ha^{-1} mulch and tembotrione at 0.088 kg ha^{-1} (14.9 and 14.8), tembotrione at 0.110 kg ha^{-1} (14.8 and 14.8) and weed free (14.7 and 14.7) each in combination with 6.25 t ha^{-1} mulch but significantly higher than all other treatment combinations. The data further revealed that lower dose of atrazine in combination with 6.25 t ha^{-1} mulch and atrazine at higher dose without mulch produced statistically similar number of rows per cob. Under no mulch treatments, tembotrione at higher dose resulted in significantly more number of rows per cob than tembotrione at lower dose, however application of tembotrione at lower dose in combination with 6.25 t ha^{-1} mulch recorded significantly more number of rows per cob as compared with tembotrione at higher dose without mulch. At both the locations, 9.0 t ha^{-1} mulch application without any herbicide (unweeded check) resulted in statistically similar number of rows per cob as compared to application of atrazine at 1.0 kg ha^{-1} without mulch, thus indicating the beneficial effect of straw mulch. Kumar and Angadi (2014) also reported that combined effect of mulch and atrazine application helped in enhancing the number of rows per cob in maize as compared to unweeded check.

4.4.5 Number of grains per cob

The number of grains per cob has a direct influence on the grain yield of maize. The data on the number of grains per cob are presented in table 4.28 which showed that number of

Table 4.28 Effect of straw mulch and weed control treatments on yield attributing characters of maize

Treatment	Yield attributing characters											
	Number of cobs plant^{-1}		Cob length (cm)		Cob girth (cm)		Number of rows cob^{-1}		Number of grains cob^{-1}		1000 grain weight (g)	
	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**
Straw mulch												
No mulch	1.00a	1.01a	16.97c	16.17c	13.19c	12.10c	13.3c	13.1c	408.8c	404.1c	263.8c	253.6c
PSM 6.25 t ha^{-1}	1.06a	1.02a	17.69b	17.59b	14.04b	12.37b	14.2b	14.1b	428.6b	422.6b	276.4b	266.6b
PSM 9.0 t ha^{-1}	1.11a	1.03a	18.11a	18.72a	14.50a	12.60a	14.5a	14.4a	441.4a	436.3a	282.2a	272.1a
Weed control												
Atrazine at 1.0kg ha^{-1}	1.00a	1.00a	17.31b	17.52b	13.80b	12.18b	14.0b	13.8b	420.0b	415.5b	273.6b	263.3b
Atrazine at 0.8 kg ha^{-1}	1.00a	1.00a	17.18b	16.68b	13.65b	12.08b	13.5c	13.4c	409.8c	404.3c	268.7c	257.7c
Tembotrione at 0.110 kg ha^{-1}	1.11a	1.02a	18.17a	18.21a	14.31a	12.69a	14.6a	14.5a	445.1a	440.3a	279.4a	270.2a
Tembotrione at 0.088 kg ha^{-1}	1.11a	1.04a	18.13a	18.27a	14.29a	12.67a	14.4a	14.3a	443.9a	438.0a	278.9a	269.3a
Weed free	1.11a	1.07a	18.34a	18.31a	14.31a	12.70a	14.5a	14.4a	445.9a	440.9a	280.6a	271.4a
Unweeded check	1.00a	1.00a	16.40c	15.98c	13.10c	11.81c	12.9d	12.8d	393.0d	387.0d	263.7d	252.7d
Interaction	NS	NS	NS	NS	NS	NS	S	S	S	S	NS	NS

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

*Ludhiana **Gurdaspur

grains per cob was significantly influenced by different straw mulch treatments. Application of 9.0 t ha^{-1} mulch resulted in maximum number of 441.4 and 436.3 grains per cob at Ludhiana and Gurdaspur, respectively which was significantly higher than 6.25 t ha^{-1} mulch (428.6 and 422.6) and no mulch treatment (408.8 and 404.1). The increase in number of grains per cob under straw mulch treatments is due to higher weed control efficiency and is supported by significantly large source size and capacity as indicated by higher number of leaves per plant, DMA, LAI and PAR interception. This better source size filled with adequate quantity of food reserves helped the plant to develop better sink size as supported by significantly more cob length and ultimately produced more number of grains per cob.

Weed control treatments significantly affected the number of grains per cob (Table 4.28). Weed free treatment produced maximum number of 445.9 and 440.9 grains per cob at Ludhiana and Gurdaspur, respectively which were statistically at par with tembotrione at 0.110 kg ha^{-1} (445.1 and 440.3) and tembotrione at 0.088 kg ha^{-1} (443.9 and 438.0) but significantly higher in comparison to atrazine at 1.0 kg ha^{-1} (420.0 and 415.5), atrazine at 0.8 kg ha^{-1} (409.8 and 404.3) and unweeded check (393.0 and 387.0) treatments. Application of atrazine at higher dose also recorded significantly more number of grains per cob in comparison to atrazine at lower dose and unweeded check at both the locations. Later two treatments also differed significantly with respect to the number of grains per cob. Similar results were reported by Barla *et al* (2016) and Gul *et al* (2016) with atrazine as pre-emergence application. Increased number of grains per cob under weed free and tembotrione at both doses was mainly due to better weed control efficiency and increased cob length, cob girth and number of rows per cob under these treatments.

The interaction was significant with respect to the number of grains per cob (Table 4.29, Fig. 4.13). The data showed that at Ludhiana and Gurdaspur, maximum number of grains per cob (462.9 and 456.7) were recorded with tembotrione at 0.088 kg ha^{-1} in combination with paddy straw mulch at 9.0 t ha^{-1} which was at par with tembotrione at 0.110 kg ha^{-1} (460.4 and 455.9) and weed free treatment (460.5 and 456.1) in combination with paddy straw mulch at 9.0 t ha^{-1} but significantly higher than all other treatment combinations. All these treatments were followed by tembotrione at both doses and weed free treatment in combination with 6.25 t ha^{-1} mulch. Weed free treatment without mulch and atrazine at higher dose in combination with 9.0 t ha^{-1} mulch resulted in statistically similar number of grains per cob. The data further revealed that atrazine at lower dose in combination with 6.25 t ha^{-1} mulch gave statistically similar number of grains per cob as obtained under atrazine at higher dose without mulch. Similarly, atrazine at lower dose in combination with 9.0 t ha^{-1} mulch recorded statistically similar number of grains per cob as obtained under atrazine at higher dose in combination with 6.25 t ha^{-1} mulch. Application of 9.0 t ha^{-1} mulch without any herbicide (unweeded check) produced statistically similar number of grains per cob as obtained under atrazine at higher dose without mulch. Under no mulch treatments, tembotrione at higher dose resulted in significantly higher number of grains per cob than tembotrione at lower dose, however tembotrione at lower dose in combination with 6.25 t ha^{-1} mulch produced significantly higher number of grains per cob than tembotrione higher dose without mulch. The data further revealed that for getting higher number of grains per cob from maize, tembotrione at both doses can be applied in combination with 9.0 t ha^{-1} mulch. Similar findings were reported by Kumar and Angadi (2014) who observed that combined effect of mulch and application of atrazine enhanced number of grains per cob in maize as compared to unweeded check.

4.4.6 1000 grain weight

Grain weight represents the development and plumpness of grains and is an important index of grain yield. The data given in table 4.28 showed that straw mulch and weed control treatments differed significantly with respect to 1000 grain weight. Among straw mulch treatments, maximum 1000 grain weight of 282.2 and 272.1 g was recorded at Ludhiana and Gurdaspur, respectively with 9 t ha^{-1} mulch application which was significantly higher than 6.25 t ha^{-1} mulch (276.4 and 266.6 g) and no mulch (263.8 and 253.6 g) treatments. Zamir *et al* (2013) and Uwah and Iwo (2011) also reported similar findings with straw mulch application in maize. Lowest 1000 grain weight was observed under no mulch treatment at both the locations. The increase in 1000 grain weight under straw mulch treatments was due to higher weed control efficiency and is supported by significantly large source size and capacity as indicated by better plant growth. This better source size filled with adequate quantity of food reserves helped the plant to develop better sink size and resulted in higher1000 grain weight.

While comparing different weed control treatments, weed free treatment produced maximum 1000 grain weight of 280.6 and 271.4 g at Ludhiana and Gurdaspur, respectively which was statistically at par with application of tembotrione at 0.110 kg ha^{-1} (279.4 and 270.2 g) and tembotrione at 0.088 kg ha^{-1} (278.9 and 269.3 g) treatments and significantly higher than atrazine at both doses and unweeded check. Lowest thousand grain weight was observed in unweeded check (263.7 and 252.7 g) at both the locations. Higher thousand grain weight under different weed control treatments might be due to less weed density and dry matter of weeds as well as better growth and development of maize plants. Similar results were reported by Barla *et al* (2016) and Gul *et al* (2016). The interaction was not significant with respect to 1000 grain weight.

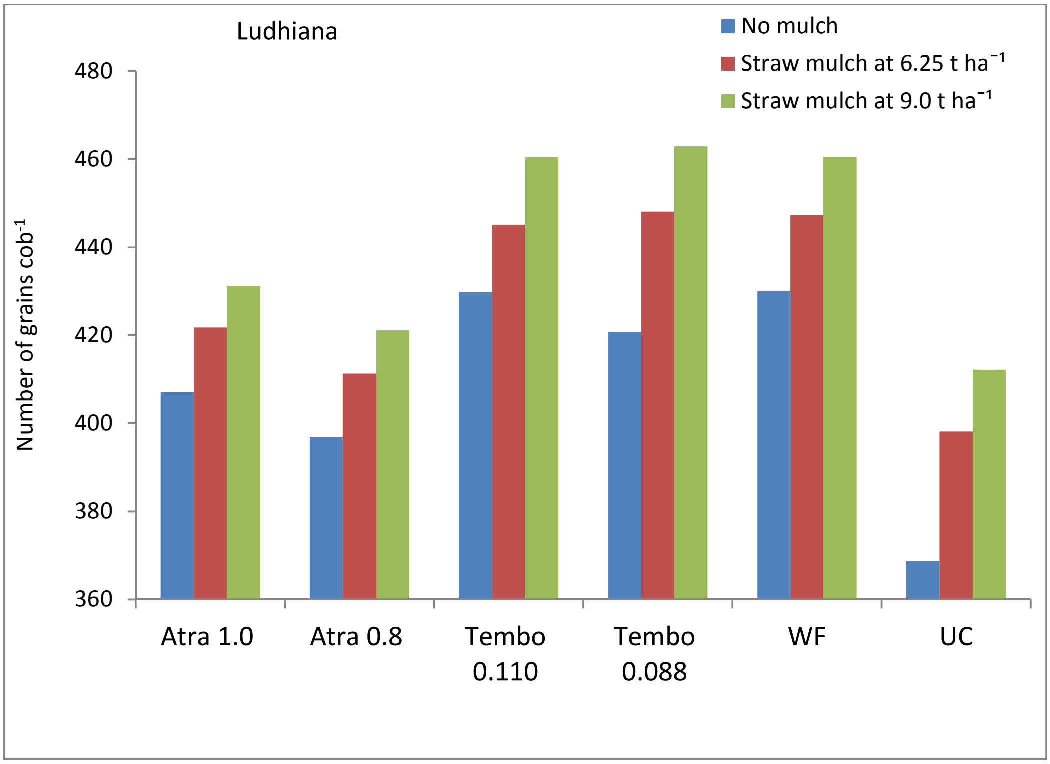
4.4.7 Grain yield

Grain yield of a crop is the net resultant of interaction of various factors and is a valid criterion for comparing the efficiency of different treatments. The crop grain yield is the sum total of growth and yield governing attributes which are ultimately influenced by the duration

Table 4.29 Interactive effect of straw mulch and weed control treatments on number of rows per cob and number of grains per cob in maize

Treatment	Number of rows cob^{-1}						Number of grains cob^{-1}					
	Ludhiana			Gurdaspur			Ludhiana			Gurdaspur		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	13.3d	14.0c	14.4b	13.2d	13.8c	14.3b	407.1e	421.7d	431.2c	405.3e	416.1d	425.2c
Atrazine at 0.8 kg ha^{-1}	12.6f	13.6d	14.2b	12.5f	13.4d	14.2b	396.9f	411.3e	421.1d	389.6f	406.2e	417.1d
Tembotrione at 0.110 kg ha^{-1}	14.1b	14.8a	14.8a	13.9b	14.8a	14.8a	429.7c	445.1b	460.4a	424.8c	440.3b	455.9a
Tembotrione at 0.088 kg ha^{-1}	13.5d	14.9a	14.9a	13.3d	14.8a	14.9a	420.7d	448.1b	462.9a	415.2d	442.0b	456.7a
Weed free	14.0c	14.7a	14.9a	13.7c	14.7a	14.8a	430.0c	447.3b	460.5a	425.1c	441.6b	456.1a
Unweeded check	12.1g	13.0e	13.5d	12.1g	12.9e	13.4d	368.7g	398.2f	412.2e	364.6g	389.3f	407.0e

- Means followed by same letters do not vary significantly at 5% level by DMRT



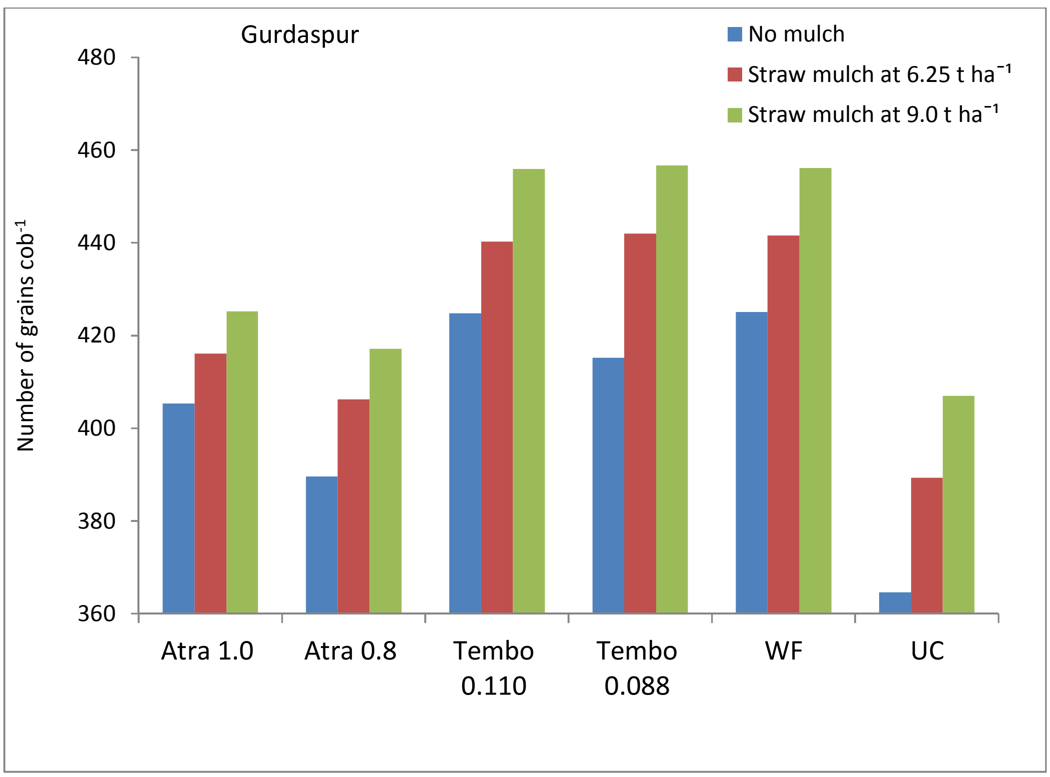


Fig. 4.13 Effect of straw mulch and weed control treatments on number of grains per cob at Ludhiana and Gurdaspur

for which the weeds remained in competition with the crop, the intensity of their infestation, dry matter accumulated by weeds at the expense of crop dry matter and type of weed species associated with the crop. The ultimate objective of all the agronomic studies is to optimize the yield of any crop. The economic yield of a crop depends on the manner in which the dry matter produced during the vegetative phase of the crop is distributed among various sinks i.e. the vegetative and reproductive parts. The data on grain yield of maize are presented in table 4.30.

Among the straw mulch treatments, application of 9.0 t ha^{-1} mulch produced significantly higher maize grain yield (62.16 and 59.09 q ha^{-1}) in comparison to 6.25 t ha^{-1} mulch (58.11 and 54.56 q ha^{-1}) and no mulch (53.14 and 48.21 q ha^{-1}) treatments at Ludhiana and Gurdaspur, respectively. Dutta *et al* (2016), Zamir *et al* (2013), Bahar *et al* (2013) and Uwah and Iwo (2011) also reported significantly higher grain yield in mulch treatments as compared to no mulch. Minimum grain yield was recorded under no mulch treatment at both the locations. Higher grain yield under straw mulch may be attributed to better above and below soil surface conditions which helped the plants for better growth through reduction in the soil temperature and resulted in better weed control efficiency and initial crop growth as evident from significantly higher plant height (Table 4.21) and higher number of leaves per plant (Table 4.21). The higher leaf number per plant with fully expanded leaf blades resulted in significantly higher values of LAI (Table 4.22) which intercepted higher proportion of PAR (Table 4.24) for the production of photosynthates. There was significantly higher accumulation of dry matter (Table 4.22) by the plants under mulch applied treatments as compared to no mulch treatment. Even during later stages of plant growth, all the yield attributing parameters recorded significantly higher values and ultimately higher grain yield was obtained under straw mulch treatments as compared to no mulch treatment. Straw mulch significantly enhanced the grain yield by 14.4 per cent as observed by Bahar (2013). Shah *et al* (2014) also reported that straw mulch recorded significantly higher grain yield than no mulch treatment.

Weed control treatments significantly influenced the grain yield of maize at both the locations (Table 4.39). Weed free treatment produced maximum grain yield of 63.21 and 59.67 q ha^{-1} at Ludhiana and Gurdaspur, respectively which were statistically at par with tembotrione at 0.088 kg ha^{-1} (62.29 and 58.62 q ha^{-1}) and tembotrione at 0.110 kg ha^{-1} (62.39 and 59.15 q ha^{-1}) but was significantly higher in comparison to atrazine at 1.0 kg ha^{-1} (56.22 and 52.66 q ha^{-1}), atrazine at 0.8 kg ha^{-1} (53.28 and 48.85 q ha^{-1}) and unweeded check (49.43 and 44.77 q ha^{-1}) treatments. Rana *et al* (2017) also found more grain yield with application of tembotrione than unweeded check. Atrazine at higher dose (1.0 kg ha^{-1}) also resulted in significantly higher grain yield in comparison to atrazine at lower dose (0.8 kg ha^{-1}) and unweeded check at both the locations. Later two treatments also differed significantly with

Table 4.30 Effect of straw mulch and weed control treatments on grain yield, stover yield, shelling percentage and harvest index in maize

Treatment	Grain yield (q ha^{-1})		Stover yield (q ha^{-1})		Shelling (%)		Harvest index (%)	
	Ludhiana	**Gurdaspur**	**Ludhiana**	**Gurdaspur**	**Ludhiana**	**Gurdaspur**	**Ludhiana**	**Gurdaspur**
Straw mulch								
No mulch	53.14c	48.21c	112.5c	114.4c	72.6a	72.7a	27.9b	25.8b
PSM 6.25 t ha^{-1}	58.11b	54.56b	127.7b	130.7b	74.0a	74.2a	28.5a	26.3a
PSM 9.0 t ha^{-1}	62.16a	59.09a	138.5a	140.9a	75.1a	75.9a	28.6a	26.8a
Weed control								
Atrazine at 1.0 kg ha^{-1}	56.22b	52.66b	126.9b	129.5b	74.5a	74.3a	28.1b	26.0b
Atrazine at 0.8 kg ha^{-1}	53.28c	48.85c	117.8c	120.9c	73.1a	73.7a	27.9bc	25.4bc
Tembotrione at 0.110 kg ha^{-1}	62.39a	59.15a	136.9a	137.4a	75.7a	76.2a	28.7a	27.0a
Tembotrione at 0.088 kg ha^{-1}	62.29a	58.62a	136.1a	137.1a	75.5a	75.9a	28.8a	26.9a
Weed free	63.21a	59.67a	137.7a	138.9a	75.7a	75.4a	29.0a	27.2a
Unweeded check	49.43d	44.77d	102.2d	105.1d	68.9a	70.0a	27.4c	24.9c
Interaction	S	S	NS	NS	NS	NS	NS	NS

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

respect to the grain yield. Barla *et al* (2016), Gul *et al* (2016), Mavunganidze *et al* (2014) and Chopra and Angiras (2008) also reported significant increase in grain yield with atrazine as pre-emergence application as compared to unweeded check. The minimum grain yield was obtained in unweeded check at both the locations. Ngouajiro *et al* (2006) and Walia *et al* (2005) also observed significant reduction in grain yield of maize under unweeded check. The higher grain yield of maize under weed free, tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1}treatments was due to higher weed control efficiency and increased growth and development in maize as indicated by higher plant height (Table 4.21), number of leaves per plant (Table 4.21) and chlorophyll content (Table 4.23). Higher number of leaves per plant resulted in higher values for LAI (Table 4.22) which captured higher photosynthetic active radiation (Table 4.24). Due to better above ground plant parts higher amount of dry matter accumulation (Table 4.22) was obtained. Thus, the photosynthesis might have taken place at an efficient level there by producing more photosynthates for better development of sink size as indicated by comparatively higher yield attributing characters. All these factors helped to fill the sink resulting in higher yield.

The interaction between straw mulch and weed control treatments was significant with respect to the grain yield (Table 4.31 and Fig. 4.14). The data showed that at both the locations of Ludhiana and Gurdaspur, application of tembotrione at both doses (0.088 and 0.110 kg ha^{-1}) and weed free treatments in combination with 9.0 t ha^{-1} mulch produced statistically similar and significantly higher grain yield of maize as compared to all other treatments combinations and these treatments were followed by tembotrione at 0.088 kg ha^{-1}, tembotrione at 0.110 kg ha^{-1} and weed free in combination with 6.25 t ha^{-1} mulch. Weed free and tembotrione at 0.110 kg ha^{-1} without mulch and atrazine at 1.0 kg ha^{-1} in combination with 9.0 t ha^{-1} mulch resulted in statistically similar grain yield of maize. Atrazine at 0.8 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch produced statistically similar grain yield as obtained under atrazine at 1.0 kg ha^{-1} without mulch. Similarly atrazine at lower dose (0.8 kg ha^{-1}) in combination with 9.0 t ha^{-1} mulch recorded statistically similar grain yield of maize as obtained with atrazine at higher dose (1.0 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch. Kumar and Angadi (2014) also observed that combined effect of mulch and application of atrazine enhanced grain yield in maize as compared to unweeded check. Application of only 9.0 t ha^{-1} mulch without any herbicide (unweeded check) produced statistically similar yield as obtained with atrazine application at 1.0 kg ha^{-1} without mulch, thus indicating the beneficial effect of straw mulch. Under no mulch conditions, tembotrione at 0.110 kg ha^{-1} produced significantly higher grain yield of maize as compared to tembotrione at 0.088 kg ha^{-1} but tembotrione at 0.088 kg ha^{-1} with combination with paddy straw mulch at 6.25 t ha^{-1} resulted in significantly higher grain yield of maize than tembotrione at 0.110 kg ha^{-1} without mulch. As statistically similar grain yield was obtained

Table 4.31 Interactive effect of straw mulch and weed control treatments on grain yield in maize

Treatment	Grain yield (q ha^{-1})					
	Ludhiana			Gurdaspur		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	53.14e	56.46d	59.05c	48.59f	52.80d	56.60c
Atrazine at 0.8 kg ha^{-1}	49.74f	53.54e	56.54d	44.50g	48.97ef	53.07d
Tembotrione at 0.110 kg ha^{-1}	58.19c	62.26b	66.71a	53.43d	59.44b	64.56a
Tembotrione at 0.088 kg ha^{-1}	55.65d	63.05b	68.16a	50.59e	60.17b	65.11a
Weed free	58.25c	63.14b	68.24a	53.22d	60.67b	65.12a
Unweeded check	43.85g	50.19f	54.25e	38.95h	45.29g	50.06ef

- Means followed by same letter do not vary significantly at 5% level by DMRT

with the application of tembotrione at 0.110 kg ha^{-1} and tembotrione at 0.088 kg ha^{-1} in combination with paddy straw mulch at 9.0 t ha^{-1}, but application of tembotrione at 0.088 kg ha^{-1} proved more beneficial as there was reduction of 20 % herbicide dose in this combination. The above findings indicated that straw mulch helped in reduction of 20 % herbicide dose both in atrazine and tembotrione besides improving in the grain yield.

The grain yield of maize had negative relationship with weed density and dry matter accumulation of weeds at harvest with respect to straw mulch and weed control treatments at both locations (Fig. 4.15, 4.16, 4.17 and 4.18). In case of straw mulch, the weed density at harvest alone explained 96 to 99.5 per cent variation in grain yield and weed dry matter accumulation at harvest alone explained 91 to 94 per cent variation in grain yield, whereas, in case of weed control treatments, the weed density at harvest alone explained 91 to 94 per cent variation in grain yield and weed dry matter accumulation at harvest alone explained 87.6 to 88.5 per cent variation in grain yield. Chauhan and Abugho (2013) also observed an inverse relationship between weed biomass and increase in mulch levels in the herbicide non-treated plots. Similarly, Rana *et al* (2017) reported that grain yield of maize was negatively correlated with DMA of total weeds. They observed that with every 1g m^{-2} increase in DMA of weeds, the maize grain yield was reduced by 33.7 kg ha^{-1}.

The maize grain yield showed positive relationship with number of grains per cob at harvest with respect to straw mulch and weed control treatments at both locations (Fig 4.19 and 4.20). In case of straw mulch, the number of grains per cob explained 99.5 to 99.9 per cent variation in grain yield, whereas, in case of weed control treatments, these explained 99.7 to 99.8 per cent variation in grain yield.

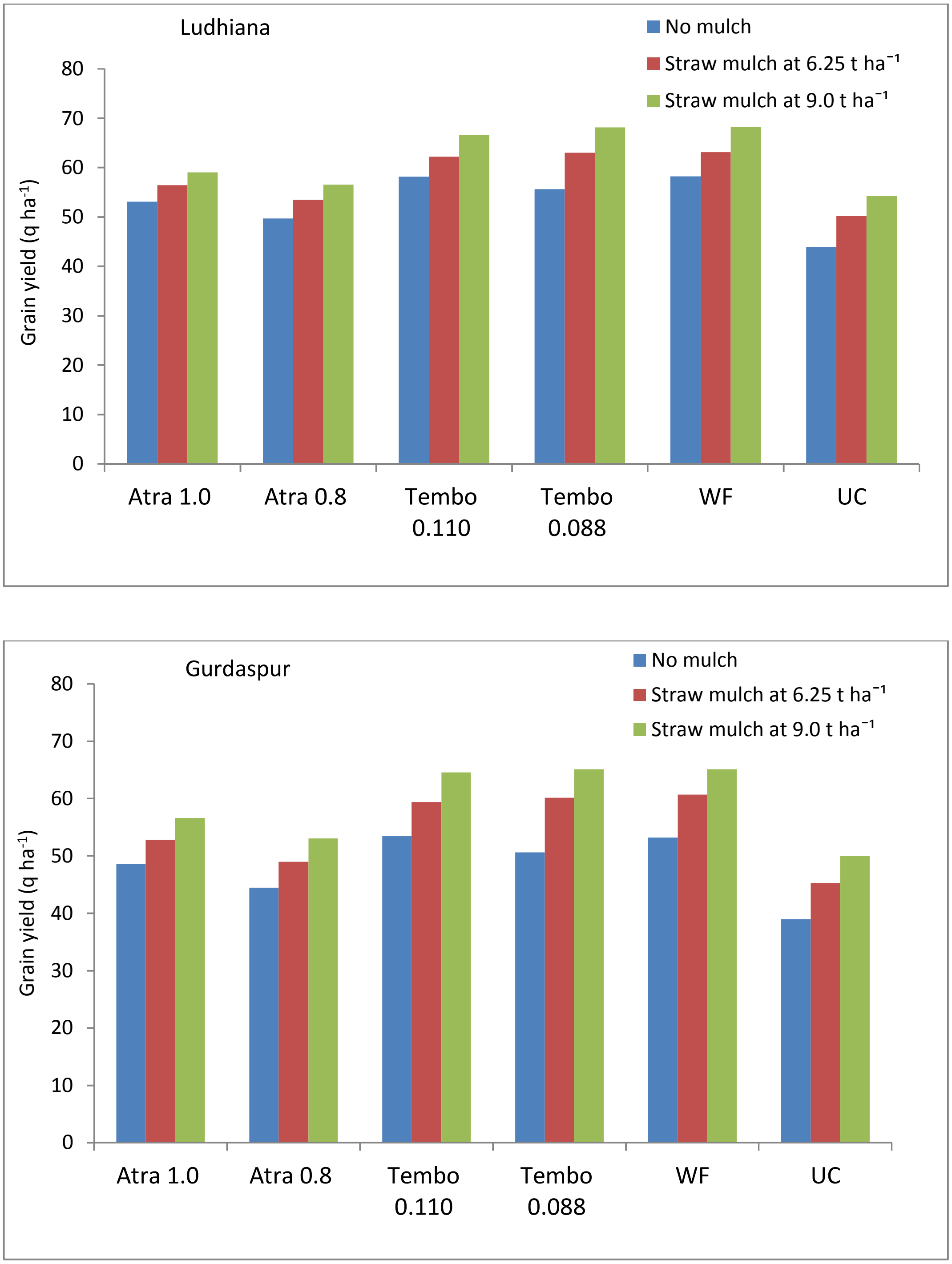


Fig. 4.14 Effect of straw mulch and weed control treatments on grain yield in maize at Ludhiana and Gurdaspur

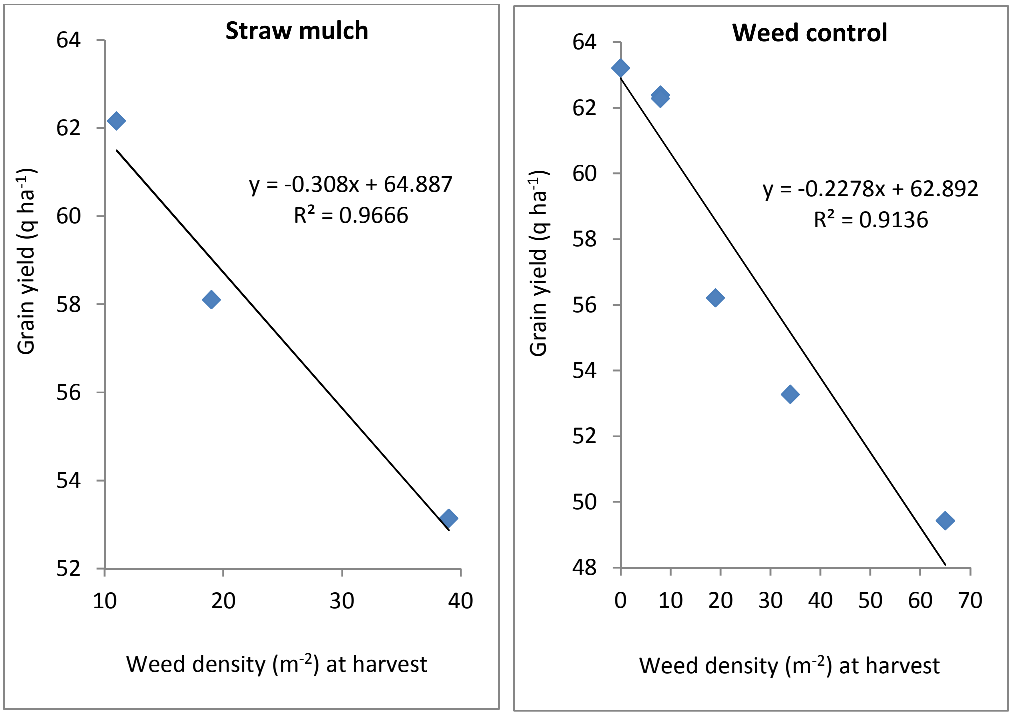


Fig. 4.15 Relationship between weed density at harvest and grain yield in maize (Ludhiana)

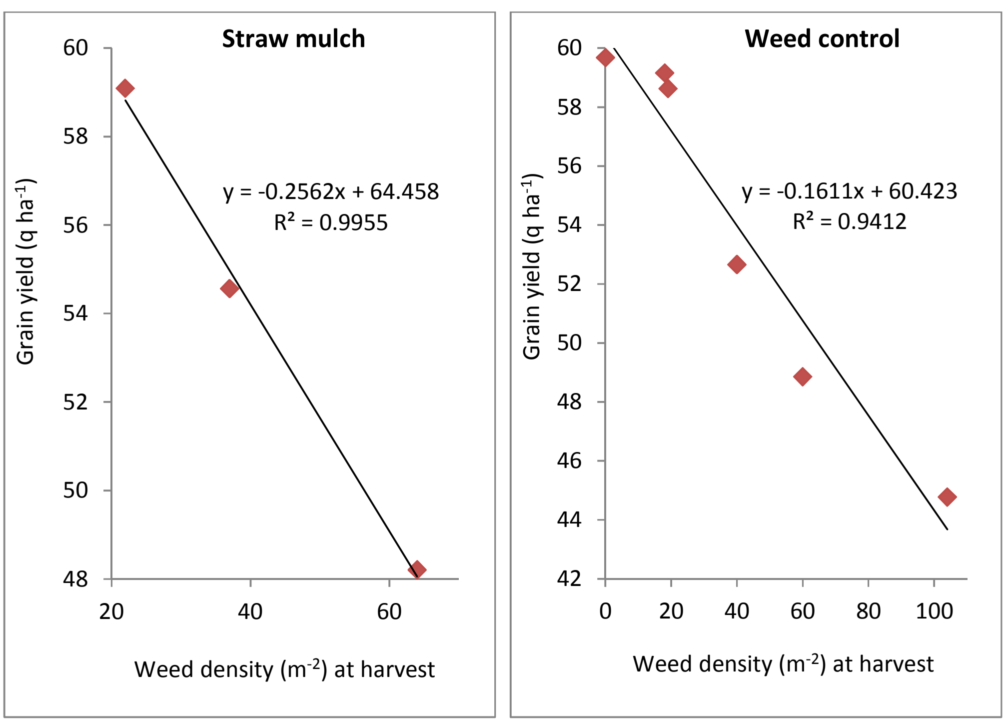


Fig. 4.16 Relationship between weed density at harvest and grain yield in maize (Gurdaspur)

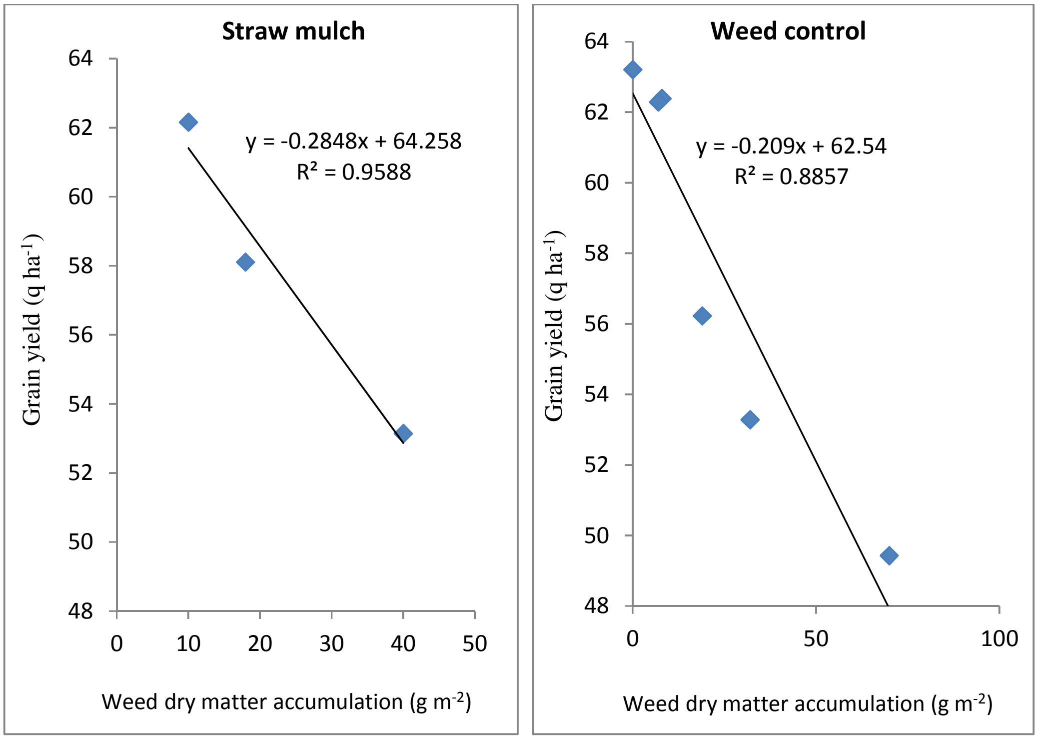


Fig. 4.17 Relationship between weed dry matter accumulation and grain yield in maize (Ludhiana)

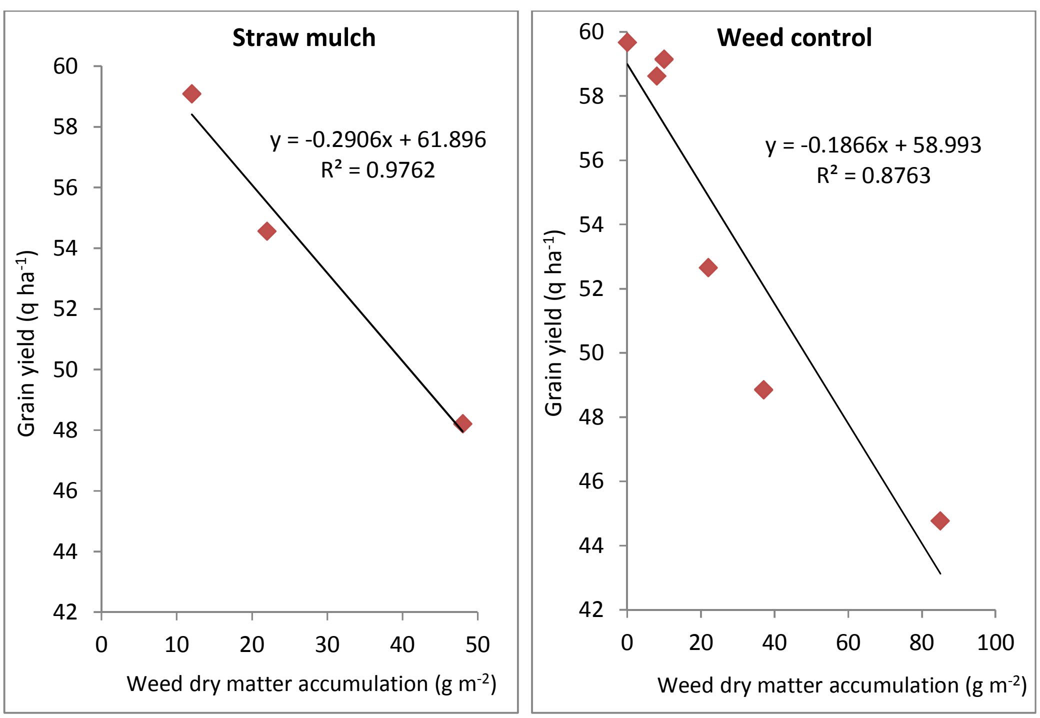


Fig. 4.18 Relationship between weed dry matter accumulation and grain yield in maize (Gurdaspur)

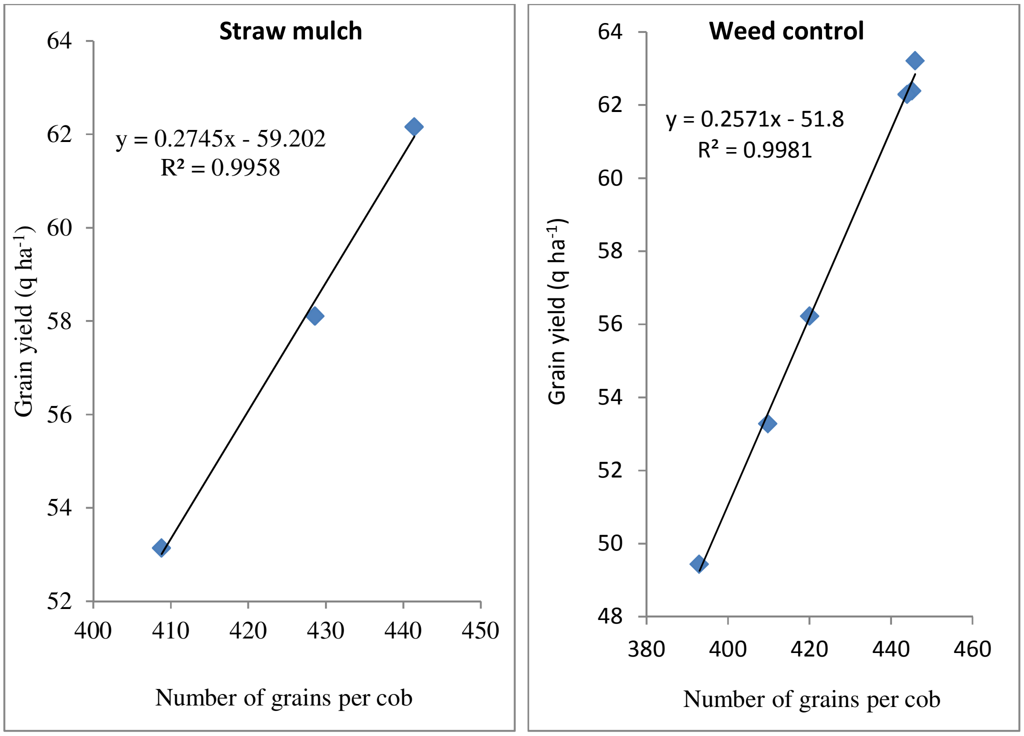


Fig. 4.19 Relationship between number of grains per cob and grain yield in maize (Ludhiana)

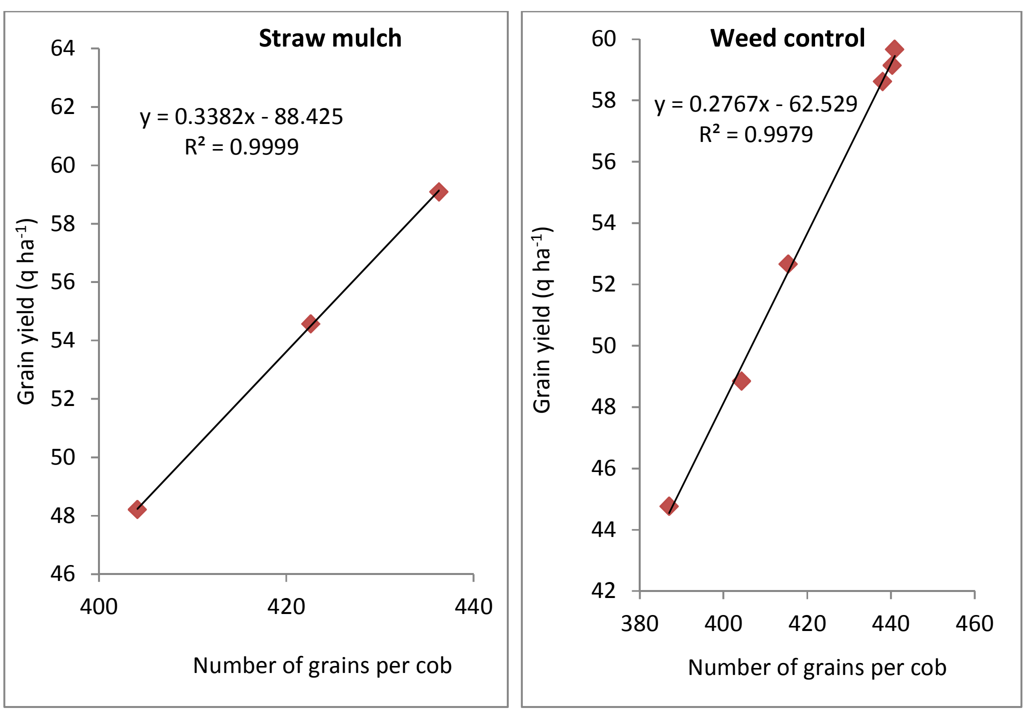


Fig. 4.20 Relationship between number of grains per cob and grain yield in maize (Gurdaspur)

4.4.8 Stover yield

Stover yield of maize has economic value as it is fed to the animals. The data given in table 4.30 revealed that straw mulch treatments showed significant effect on the stover yield. Mulch 9.0 t ha^{-1} resulted in significantly more stover yield as compared to 6.25 t ha^{-1} and no mulch treatments. Similarly 6.25 t ha^{-1} mulch also produced significantly higher stover yield than unweeded check. Lowest stover yield was recorded under no mulch treatment at both the locations. Enhanced stover yield under straw mulch applied treatments might be attributed to better above and below soil surface conditions which may helped to increase the stover yield attributed to increase in height, leaves per plant and dry matter accumulation by the plants and reduction in the soil temperature. Uwah and Iwo (2011) also reported significant higher stover yield under mulch treatments as compared to no mulch.

Among the weed control treatments, maximum stover yield (137.7 and 138.9 q ha^{-1}) was recorded under weed free treatment which was statistically at par with tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} but was significantly better than atrazine at 1.0 kg ha^{-1} and atrazine at 0.8 kg $ha^{-1}$and unweeded check, the latter three also differed significantly with each other. Similar results on stover yield were reported by Sahoo *et al* (2016) and Gul *et al* (2016) with atrazine as pre-emergence application. Lowest stover yield (102.2 and 105.1 q ha^{-1}) was recorded under unweeded check treatment at both the locations. The higher stover yield under weed free and tembotrione at both doses was attributed to higher WCE as well as higher plant growth as indicated by increase in growth parameters as compared to all other treatments. The interaction effect was not significant.

4.4.9 Shelling percentage

The data on shelling percentage are presented in table 4.30 which showed that straw mulch treatments did not significantly influence the shelling percentage at both the locations. However, numerically higher values of shelling percentage were observed under 9.0 t ha^{-1} mulch application followed by 6.25 t ha^{-1} and no mulch treatments.

Similarly, different weed control treatments did not significantly influence the shelling percentage at both the locations. The interaction was not significant with respect to shelling percentage.

4.4.10 Harvest index

Harvest index is an indicator of efficiency of crop plants to translocate manufactured food material at source level to the sink or grains. The data pertaining to harvest index are presented in table 4.30 which showed that harvest index was significantly affected by straw mulch treatments. Application of 9.0 t ha^{-1} mulch resulted in significantly higher harvest index as compared to no mulch treatment but remained statistically at par with 6.25 t ha^{-1} mulch at both the locations. Higher harvest index under these straw mulch treatments was attributed to higher grain yield as indicated by better growth and development of maize plants as compared to no mulch treatment.

Different weed control treatments significantly influenced the harvest index at both the locations (Table 4.30). Maximum harvest index of 29.0 and 27.2 % was recorded under weed free treatment at Ludhiana and Gurdaspur, respectively which was statistically at par with tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} but significantly higher than atrazine at both doses and unweeded check. Lowest harvest index (27.4 and 24.9 %) was observed under unweeded check at both the locations. Higher harvest index under these weed control treatments was attributed to lower weed density and dry matter of weeds that ultimately increased the grain yield due to better growth and development of maize plants as compared to unweeded check. The interaction between straw mulch and weed control treatments was not significant with respect to harvest index in maize.

4.5 Quality analysis

4.5.1 Protein content

Protein content is one of the most important quality characters of grains. The data on protein content of grains are given in table 4.32 which revealed that protein content in maize grains was not significantly influenced by different straw mulch and weed control treatments at both the locations.

Table 4.32 Effect of straw mulch and weed control treatments on protein and oil content of maize

Treatment	Quality parameters			
	Protein content (%)		Oil content (%)	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch				
No mulch	10.43a	9.38a	4.04a	3.87a
PSM 6.25 t ha^{-1}	10.87a	10.04a	4.15a	3.96a
PSM 9.0 t ha^{-1}	10.97a	10.46a	4.29a	4.05a
Weed control				
Atrazine at 1.0 kg ha^{-1}	10.69a	9.97a	4.16a	3.95a
Atrazine at 0.8 kg ha^{-1}	10.55a	9.65a	4.11a	3.82a
Tembotrione at 0.110 kg ha^{-1}	11.09a	10.44a	4.22a	4.09a
Tembotrione at 0.088 kg ha^{-1}	11.14a	10.49a	4.24a	4.08a
Weed free	11.13a	10.47a	4.22a	4.10a
Unweeded check	9.94a	8.73a	3.99a	3.72a

- Means followed by same letter do not vary significantly at 5% level by DMRT

4.5.2 Oil content

Data on oil content of maize grains are presented in table 4.32 which indicated that different mulch treatments did not significantly influence the oil content of maize grains at both the locations. However, numerically higher values of oil content of maize grains was observed under 9.0 t ha^{-1} mulch which was followed by 6.25 t ha^{-1} and no mulch treatments. Similarly, oil content of maize grains was not significantly affected by different weed control treatments at both the locations.

4.6 Economics

4.6.1 Gross returns

The data pertaining to the gross returns are presented in table 4.33. The straw mulch significantly influenced the gross returns in maize. At Ludhiana and Gurdaspur, maximum gross returns (₹ 104.5×10^3 and 99.0 ×10^3 ha^{-1}) were obtained under application of 9.0 t ha^{-1} mulch which was significantly better than 6.25 t ha^{-1} mulch (₹ 95.5 ×10^3 and 91.4 ×10^3 ha^{-1}) and no mulch (₹ 88.7 ×10^3 and 80.5 ×10^3 ha^{-1}) treatments. Higher gross returns under these straw mulch treatments was attributed to higher grain and stover yield due to better growth and development of maize plants as compared to no mulch treatment.

Weed control treatments significantly influenced the gross returns at both the locations. Weed free treatment produced maximum gross returns (₹ 105.9×10^3 and 99.6 ×10^3 ha^{-1}) which were statistically at par with tembotrione at 0.088 kg ha^{-1} (₹ 104.5×10^3 and 98.0 ×10^3 ha^{-1}) and tembotrione at 0.110 kg ha^{-1} (₹ 104.6×10^3 and 98.7 ×10^3 ha^{-1}) but was significantly higher than atrazine at 1.0 kg ha^{-1} (₹ 94.7 ×10^3 and 88.6 ×10^3 ha^{-1}), atrazine at 0.8 kg ha^{-1} (₹ 89.5 ×10^3 and 82.1 ×10^3 ha^{-1}) and unweeded check (₹ 82.2 ×10^3 and 74.8 ×10^3 ha^{-1}). Higher gross returns under these weed control treatments was attributed to better weed

Table 4.33 Effect of straw mulch and weed control treatments on gross returns, net returns and benefit cost ratio in maize

Treatment	Gross returns (×10^3, ₹ ha^{-1})		Net returns (×10^3, ₹ ha^{-1})		Benefit cost ratio	
	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur
Straw mulch						
No mulch	88.7c	80.5c	49.6c	41.4c	1.28c	1.07c
PSM 6.25 t ha^{-1}	95.5b	91.4b	57.2b	51.1b	1.42b	1.27b
PSM 9.0 t ha^{-1}	104.5a	99.0a	62.9a	57.4a	1.51a	1.38a
Weed control						
Atrazine at 1.0 kg ha^{-1}	94.7b	88.6b	55.4c	49.3c	1.41b	1.25b
Atrazine at 0.8 kg ha^{-1}	89.5c	82.1c	50.6d	43.3d	1.30c	1.14c
Tembotrione at 0.110 kg ha^{-1}	104.6a	98.7a	65.1a	59.2a	1.65a	1.49a
Tembotrione at 0.088 kg ha^{-1}	104.5a	98.0a	65.2a	58.7a	1.66a	1.49a
Weed free	105.9a	99.6a	59.3b	53.0b	1.28c	1.11c
Unweeded check	82.2d	74.8d	43.7e	36.4e	1.13d	0.94d
Interaction	S	S	S	S	S	S

- In a column, means followed by same letter do not vary significantly at 5% level by DMRT

control efficiency and higher grain and stover yield of maize as compared to unweeded check.

The interaction between straw mulch and weed control treatments was significant with respect to gross returns (Table 4.34). The data showed that at Ludhiana and Gurdaspur, maximum gross returns (₹ 114.6×10^3 and 108.7 ×10^3 ha^{-1}) were recorded under weed free treatment in combination with 9.0 t ha^{-1} mulch which was statistically at par with application of tembotrione at 0.088 kg ha^{-1} (₹ 114.4×10^3 and 108.6 ×10^3 ha^{-1}) and tembotrione at 0.110 kg ha^{-1} (₹ 112.2×10^3 and 107.7 ×10^3 ha^{-1}) in combination with paddy straw mulch at 9.0 t ha^{-1} but was significantly higher than all other treatments combinations. All these treatments were followed by weed free and tembotrione at both doses in combination with 6.25 t ha^{-1} mulch with respect to gross returns. Weed free treatment without mulch and atrazine at higher dose in combination with 6.25 t ha^{-1} mulch resulted in statistically similar gross returns. The data further indicated that atrazine at lower dose in combination with paddy straw mulch at 6.25 t ha^{-1} gave statistically similar gross returns as obtained under atrazine at higher dose (1.0 kg ha^{-1}) without mulch. Similarly, atrazine at lower dose (0.8 kg ha^{-1}) in combination with paddy straw mulch at 9.0 t ha^{-1} recorded statistically similar gross returns as obtained under atrazine at higher dose in combination with 6.25 t ha^{-1} mulch. Mulch application 9.0 t ha^{-1} without any herbicide (unweeded check) resulted in statistically similar gross returns as obtained under atrazine at higher dose without mulch. Under no mulch treatments, tembotrione at higher dose (0.110 kg ha^{-1}) recorded significantly more gross returns than tembotrione at lower dose, however lower dose of tembotrione in combination with 6.25 t ha^{-1} mulch recorded significantly higher gross returns than tembotrione at higher dose without mulch. The data further revealed that for getting higher gross returns from maize, tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} can be applied in combination with 9.0 t ha^{-1} mulch application.

4.6.2 Net returns

The data given in the table 4.33 revealed that net returns were significantly influenced by straw mulch. At Ludhiana and Gurdaspur, 9.0 t ha^{-1} mulch application resulted in maximum net returns (₹ 62.9 ×10^3 and 57.4 ×10^3 ha^{-1}) and was significantly higher as compared to 6.25 t ha^{-1} mulch (₹ 57.2 ×10^3 and 51.1 ×10^3 ha^{-1}) and no mulch (₹ 49.6 ×10^3 and 41.4 ×10^3 ha^{-1}) treatment. Higher net returns under these straw mulch treatments was attributed to higher grain and stover yield due to better growth and development of maize plants as compared to no mulch treatment. Shah *et al* (2014) and Bahar (2013) reported that straw mulch treatments recorded significantly higher net returns than no mulch treatment.

Weed control treatments significantly influenced the net returns at both the locations. Application of tembotrione at 0.088 kg ha^{-1} (₹ 65.2×10^3 and 58.7 ×10^3 ha^{-1}) recorded statistically similar net returns with tembotrione at 0.110 kg ha^{-1} (₹ 65.1 ×10^3 and 59.2 ×10^3 ha^{-1}) and both these treatments were significantly better with respect to net returns as compared to weed free (₹ 59.3×10^3 and 53.0 ×10^3 ha^{-1}), atrazine at 1.0 kg ha^{-1} (₹ 55.4×10^3 and 49.3 ×10^3 ha^{-1}), atrazine at 0.8 kg ha^{-1} (₹ 50.6 ×10^3 and 43.3×10^3 ha^{-1}) and unweeded check (₹ 43.7 ×10^3 and 36.4 ×10^3 ha^{-1}) treatments. The data showed that minimum net returns were obtained under unweeded check at both the locations. Higher net returns under these weed control treatments were attributed to better weed control efficiency and higher grain and stover yield of maize as compared to unweeded check. Similar results were reported by Barla *et al* (2016).

The interaction was significant with respect to net returns in maize (Table 4.34 and Fig. 4.21). The data showed that at Ludhiana and Gurdaspur, maximum net returns (₹ 73.5×10^3 and 67.7 ×10^3 ha^{-1}) were recorded with tembotrione at 0.088 kg ha^{-1} in combination with paddy straw mulch at 9.0 t ha^{-1} which was statistically similar with tembotrione at 0.110 kg ha^{-1} in combination with 9.0 t ha^{-1} straw mulch (₹ 71.1×10^3 and 66.6 ×10^3 ha^{-1}) but significantly higher than all other treatment combinations. Both these treatments were followed by weed free treatment in combination with 9.0 t ha^{-1} mulch and tembotrione at both doses in combination with 6.25 t ha^{-1} mulch. The data further revealed that atrazine at 0.8 kg ha^{-1} in combination with paddy straw mulch at 6.25 t ha^{-1} and atrazine at 1.0 kg ha^{-1} without mulch recorded statistically similar net returns. Kumar and Angadi (2014) also reported that mulch in combination with atrazine application enhanced the net returns in maize. Similarly, atrazine at lower dose (0.8 kg ha^{-1}) in combination with paddy straw mulch at 9.0 t ha^{-1} gave significantly higher net returns than both atrazine at lower dose in combination with paddy straw mulch at 6.25 t ha^{-1} and atrazine at higher dose (1.0 kg ha^{-1}) without mulch treatments but was at par with combination of atrazine at higher dose with 6.25 t ha^{-1} mulch. Under no mulch conditions, tembotrione at 0.110 kg ha^{-1} recorded significantly higher net returns than tembotrione at 0.088 kg ha^{-1}, however tembotrione at lower dose (0.088 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch application gave significantly higher net returns than tembotrione at higher dose (0.110 kg ha^{-1}) without mulch. The data indicated that for getting higher net returns from maize, tembotrione at both doses can be applied in combination with 9.0 t ha^{-1} mulch. Application of 9.0 t ha^{-1} mulch without any herbicide (unweeded check) resulted in statistically similar net returns in comparison to atrazine at 1.0 kg ha^{-1} without mulch, thus indicating the benefits of straw mulch. Similarly, Dutta *et al* (2016) also reported that application of straw mulch showed the favourable effect on growth of non-symbiotic N-fixing and phosphate-solubilizing bacteria of soil, which further helped to increase net returns.

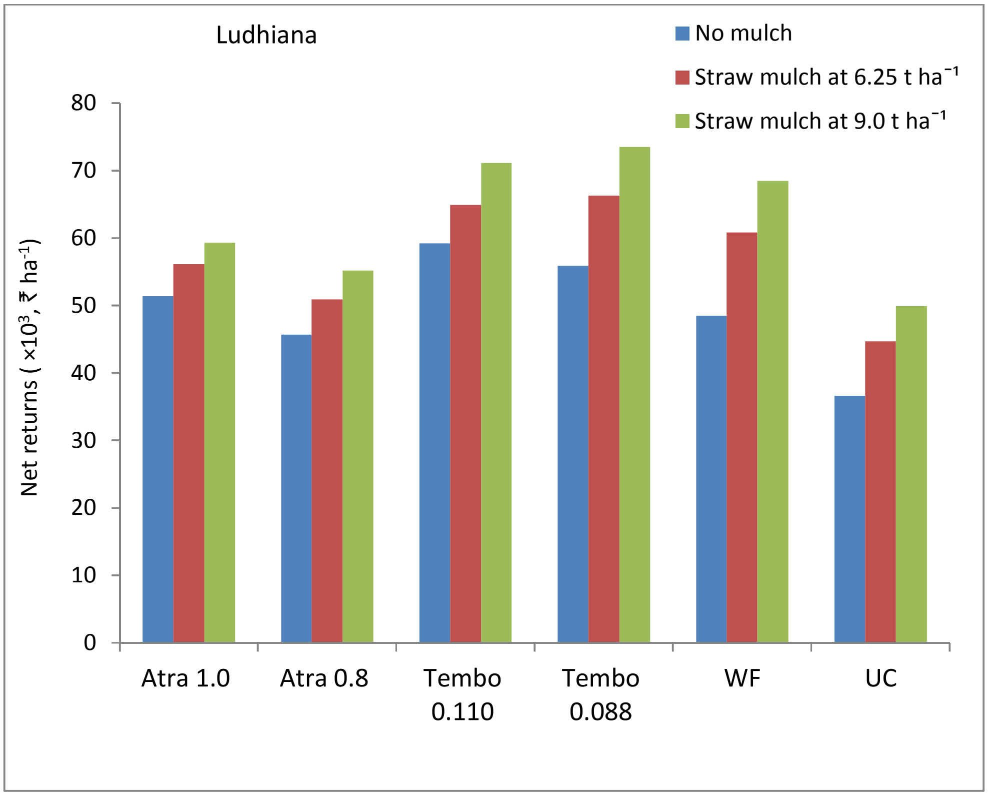
4.6.3 Benefit cost ratio

The data pertaining to the benefit cost ratio are presented in table 4.33 which showed that straw mulch significantly influenced the benefit cost ratio in maize. Application of straw mulch at 9.0 t ha^{-1} resulted in significantly more values of benefit cost ratio (1.51 and 1.38) at

Table 4.34 Interactive effect of straw mulch and weed control treatments on gross and net returns in maize

Treatment	Gross returns ($\times 10^3$, ₹ ha^{-1})						Net returns ($\times 10^3$, ₹ ha^{-1})					
	Ludhiana			Gurdaspur			Ludhiana			Gurdaspur		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	88.8f	95.2d	100.1c	81.1f	88.9d	95.6c	51.4f	56.1d	59.3c	43.7f	49.4d	54.7c
Atrazine at 0.8kg ha^{-1}	82.7g	90.0f	95.7d	74.2g	82.4f	89.7d	45.7g	50.9f	55.2d	37.2g	43.3f	49.2d
Tembotrione at 0.110 kg ha^{-1}	96.8d	104.6b	112.2a	88.9d	99.4b	107.7a	59.2d	65.0b	71.1a	51.3d	59.6b	66.6a
Tembotrione at 0.088 kg ha^{-1}	93.3e	105.8b	114.4a	84.9e	100.4b	108.6a	55.9e	66.3b	73.5a	47.5e	60.8b	67.7a
Weed free	97.0d	106.0b	114.6a	88.8d	101.3b	108.7a	48.5g	60.8c	68.5b	40.2g	56.2c	62.6b
Unweeded check	73.2h	83.4g	90.0f	64.9h	75.9g	83.7f	36.6h	44.7g	49.9f	28.3h	37.2g	43.6f

- Means followed by same letters do not vary significantly at 5% level by DMRT



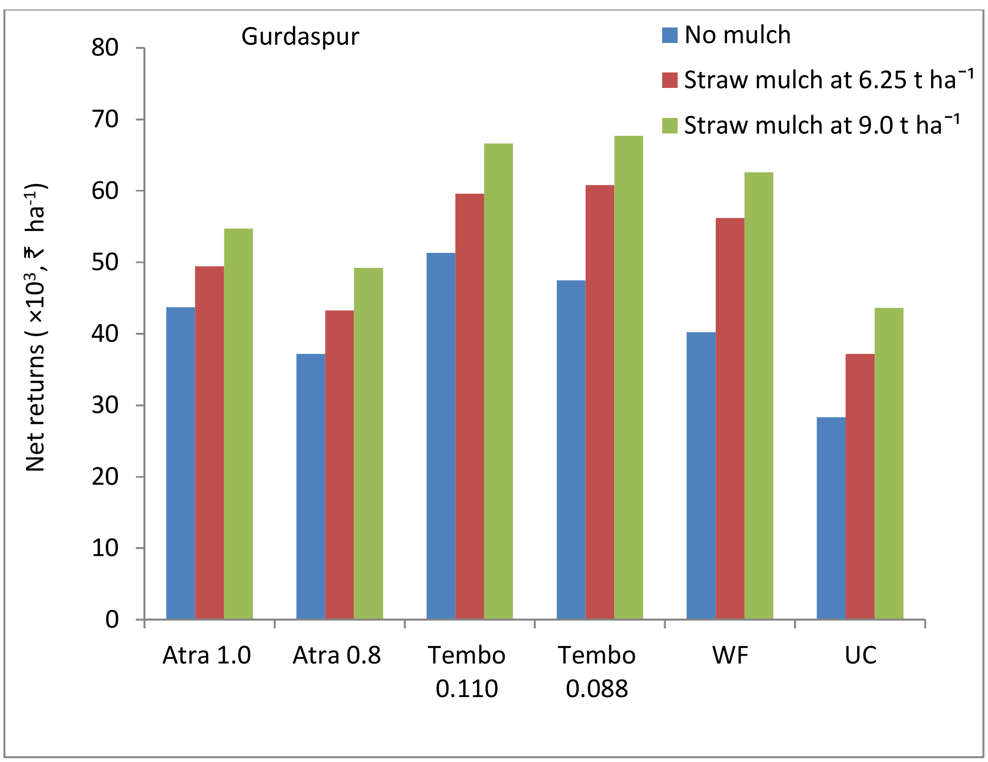


Fig. 4.21 Effect of straw mulch and weed control treatments on net returns in maize at Ludhiana and Gurdaspur

Ludhiana and Gurdaspur, respectively as compared to straw mulch at 6.25 t ha^{-1} and no mulch. Lowest benefit cost ratio (1.28 and 1.07) was observed under no mulch treatment at both the locations. Higher benefit cost ratio under these straw mulch treatments was attributed to higher grain and stover yield due to better growth and development of maize plants as compared to no mulch treatment. Bahar (2013) also observed that straw mulch application recorded the significantly higher benefit cost ratio as compared to no mulch treatment.

Weed control treatments significantly influenced the benefit cost ratio at both the locations. Maximum benefit cost ratio of 1.66 and 1.49 was recorded under tembotrione at 0.088 kg ha^{-1} treatment at Ludhiana and Gurdaspur, respectively which was at par with tembotrione at 0.110 kg ha^{-1}(1.65 and 1.49) and significantly better than atrazine at 1.0 kg ha^{-1} (1.41 and 1.25), weed free (1.28 and 1.11), atrazine at 0.8 kg ha^{-1} (1.30 and 1.14) and unweeded check (1.13 and 0.94) treatments. Rana *et al* (2017) also reported that maximum benefit cost ratio was obtained with application of tembotrione. Higher benefit cost ratio under these weed control treatments was attributed to better weed control efficiency and higher grain and stover yield of maize as compared to unweeded check. Similar results were reported by Barla *et al* (2016).

The interaction between straw mulch and weed control treatments was significant (Table 4.35) which showed that at Ludhiana and Gurdaspur, maximum benefit cost ratio (1.80 and 1.65) was observed with tembotrione at 0.088 kg ha^{-1} in combination with paddy straw mulch at 9.0 t ha^{-1} which was statistically similar with tembotrione at 0.110 kg ha^{-1} in combination with straw mulch at 9.0 t ha^{-1} (1.73 and 1.62) but significantly higher than all other treatment combinations. Both these treatments were followed by combination of tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} each with paddy straw mulch

Table 4.35 Interactive effect of straw mulch and weed control treatments on benefit cost ratio in maize

Treatment	Benefit cost ratio					
	Ludhiana			Gurdaspur		
	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}	No mulch	PSM 6.25 t ha^{-1}	PSM 9.0 t ha^{-1}
Atrazine at 1.0 kg ha^{-1}	1.27e	1.36d	1.45c	1.17e	1.25d	1.34c
Atrazine at 0.8 kg ha^{-1}	1.13f	1.26e	1.36d	1.00f	1.11e	1.21d
Tembotrione at 0.110 kg ha^{-1}	1.48c	1.63b	1.73a	1.36c	1.50b	1.62a
Tembotrione at 0.088 kg ha^{-1}	1.39d	1.64b	1.80a	1.27d	1.54b	1.65a
Weed free	0.90g	1.35d	1.49c	0.83g	1.24d	1.36c
Unweeded check	0.85g	1.15f	1.24e	0.77g	0.96f	1.09e

- Means followed by same letter do not vary significantly at 5% level by DMRT at 6.25 t ha^{-1} with respect to the benefit cost ratio. The data indicated that atrazine at 0.8 kg ha^{-1} in combination with paddy straw mulch at 6.25 t ha^{-1} and atrazine at 1.0 kg ha^{-1} without mulch recorded statistically similar benefit cost ratio. Similarly, only 9.0 t ha^{-1} mulch gave statistically similar benefit cost ratio as obtained under atrazine at higher dose without mulch. Under no mulch treatments, tembotrione at 0.110 kg ha^{-1} recorded significantly higher benefit cost ratio than tembotrione at 0.088 kg ha^{-1}, whereas tembotrione at 0.088 kg ha^{-1} in combination with 6.25 t ha^{-1} mulch gave significantly higher benefit cost ratio than tembotrione at 0.110 kg ha^{-1} without mulch. It is clear from the data that tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} in combination with paddy straw mulch 9.0 t ha^{-1} are best herbicide-mulch combinations for getting higher benefit cost ratio.

Weed Index

It measures efficacy of particular treatment in comparison with weed free treatment. Higher value of weed index means greater loss due to weeds. Weed index was calculated and are presented in table 4.36. At Ludhiana and Gurdaspur, lowest values of weed index (8.9 and 9.3 %) was obtained with the application of paddy straw mulch at 9.0 t ha^{-1} followed by straw mulch at 6.25 t ha^{-1} (14.8 and 16.2 %) and no mulch (22.1 and 26.0 %) treatments. Application of 6.25 t ha^{-1} mulch also resulted in lower values of weed index as compared to no mulch treatment. Thus, indicating the benefit of straw mulch for reducing the value of weed index in maize. Dutta *et al* (2016) reported that straw mulch helped to reduce values of weed index as compared to no mulch.

Table 4.36 Effect of straw mulch and weed control treatments on weed index in maize

Treatment	Weed index (%)	
	Ludhiana	Gurdaspur
Straw mulch		
No mulch	22.1	26.0
PSM 6.25 t ha^{-1}	14.8	16.2
PSM 9.0 t ha^{-1}	8.9	9.3
Weed control		
Atrazine at 1.0 kg ha^{-1}	17.6	19.1
Atrazine at 0.8 kg ha^{-1}	21.9	25.0
Tembotrione at 0.110 kg ha^{-1}	8.6	9.1
Tembotrione at 0.088 kg ha^{-1}	8.7	9.9
Weed free	-	-
Unweeded check	27.6	31.2

At both the locations, higher values of weed index (27.6 and 31.2 %) was recorded under unweeded check which were comparatively more than all other weed control treatments due to more weed pressure that resulted in greater loss of grain yield. All herbicides performed better in comparison to unweeded check with respect to the weed index. Among herbicide treatments, comparatively lower values of weed index viz. 8.7 and 9.9 %, respectively at Ludhiana and Gurdaspur were recorded with the application of tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} (8.6 and 9.1 %) as compared to atrazine at 1.0 kg ha^{-1} (17.6 and 19.1 %) and atrazine at 0.8kg ha^{-1} (21.9 and 25.0 %). Lower weed index under tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} may be attributed to fewer losses due to weeds because they effectively controlled weeds as compared to other weed control treatments. Rana *et al* (2017) also reported lower values of weed index with the application of tembotrione as post-emergence herbicide.

CHAPTER V

SUMMARY

Maize (*Zea mays* L.) is an important cereal crop next to wheat and rice in the world. It is used as green fodder at early stages, baby corn at very early cob stage, green cob at late milk to dough stage, maize grains as pop corn and maize flour for chapatti making. This crop provides a good quality feed for piggery, poultry and milch animals and also serves as a source of basic raw material for number of industrial products. Among the various factors responsible for low yields in maize, severe infestation of weeds due to wider row to row spacing and coincidence of crop with rainy season, often inflict huge losses in yield, may be up to 100% (Sharma 2005). Worldwide, maize production is reduced to about 40% due to competition from weeds. Weeds in maize are mainly managed by using herbicides and through manual weeding. In absence of manual weeding, farmers in irrigated areas mainly rely on herbicides to control weeds. Sequential use of pre- and post-emergent herbicides at temporal variation may help in avoiding the problem of weeds throughout the maize growth stages (Sahoo *et al* 2016). To reduce dependence on herbicides, non-chemical measures of weed management are also gaining importance. Among non-chemical measures, crop residues such as mulches, may selectively provide weed suppression through the physical presence on soil surface and show positive effects on moisture, heat and also restrict the evaporation losses (Choudhary and Kumar 2014). Different herbicides have been recommended for weed control in maize, that are used alone or in combination. Though mulch application plays an important role in suppressing the weed flora, but its efficacy for controlling the weeds may vary at different mulch levels and its combination with either pre-emergence or post emergence herbicides, this knowledge is lacking under Punjab conditions. In order to devise an integrated weed management strategy for maize, therefore, the present study on straw mulch in combination with herbicides was planned with the following objectives:

1. To study the effect of straw mulch and herbicides on weed dynamics in maize.
2. To assess the effect of straw mulch and herbicides on growth and yield of maize.

To meet these objectives, the field experiment entitled, "Weed management in maize (*Zea mays* L.) using straw mulch and herbicides" was conducted at Students' Research Farm, Department of Agronomy, PAU, Ludhiana and Regional Research Station, Gurdaspur during *kharif* 2017. The research trial was conducted in Factorial Randomized Block Design with three replications. There were three mulch treatments as first factor and six weed control treatments were taken as second factor. The predominant weed species observed at the experimental site of Ludhiana were *Dactyloctenium aegyptium, Eleusine indica, Commelina benghalensis, Eragrostis tenella, Digitaria sanguinalis, Acrachne racemosa* and *Echinochloa* *colona* as grasses, *Trianthema portulacastrum, Portulaca oleracea, Digera arvensis* and *Mollugo nudicaulis* as broadleaf weeds and *Cyperus rotundus* and *Cyperus compressus* as sedges. Whereas at Gurdaspur the predominant weed species recorded were *Dactyloctenium aegyptium, Eleusine indica, Commelina benghalensis, Cynodon dactylon* and *Eragrostis tenella* as grasses, *Trianthema portulacastrum, Digera arvensis, Euphorbia hirta, Alternanthera philoxeroides, Phyllanthus niruri, Amaranthus viridis, Veronica agrestis* and *Conyza stricta* as broadleaf weeds and *Cyperus rotundus* as sedge. The salient findings of the experiment are summarized below:

Straw mulch

Application of paddy straw mulch at 9.0 t ha^{-1} effectively controlled *D. aegyptium, C. benghalensis, E. tenella, A. racemosa, E. crusgalli*, *T. portulacastrum, D. arvensis, M. nudicaulis*, *C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, C. benghalensis, C. dactylon, T. portulacastrum, D. arvensis, E. hirta, A. philoxeroides* and *C. rotundus* at Gurdaspur as compared to other treatments. Similarly both 6.25 and 9.0 t ha^{-1} mulch treatments were statistically similar but significantly better in controlling the *E. indica, D. sanguinalis* and *E. colona* at Ludhiana and *E. indica, C. benghalensis* and *P. niruri* at Gurdaspur as compared to no mulch treatment. At 20, 40 DAS and at harvest, application of 9.0 t ha^{-1} mulch recorded significantly lowest density and dry weed matter accumulation of grasses, broadleaf weeds and sedges as compared to 6.25 t ha^{-1} and no mulch treatments at Ludhiana and Gurdaspur. Similarly, application of 6.25 t ha^{-1} mulch also recorded significantly less weed density as compared to no mulch treatment. Highest density of grasses, broadleaf weeds and sedges was recorded under no mulch treatment. Paddy straw mulch at 9.0 t ha^{-1} resulted in highest weed control efficiency (95.8 and 93.9 %) as compared to 6.25 t ha^{-1} mulch (90.5 and 88.8 %) and no mulch (69.7 and 73.5 %) treatments at Ludhiana and Gurdaspur. However, lowest weed index was obtained with 9.0 t ha^{-1} mulch application followed by 6.25 t ha^{-1} and no mulch treatments.

Plant stand was not significantly influenced by straw mulch. A sharp increase in plant height was observed between 30 to 60 DAS, which was considered as the grand growth period of crop growth. Plant height was significantly increased under straw mulch at 6.25 and 9.0 t ha^{-1}as compared to no mulch treatment. Increase in plant height of maize under straw mulch treatments was attributed to better conservation of soil moisture, low temperature and smothering effect on weeds. Both 6.25 and 9.0 t ha^{-1} mulch treatments registered significantly higher leaves per plant and DMA as compared to no mulch at 30, 60 and 90 DAS. Maximum LAI of 1.80, 5.17 and 5.20 at Ludhiana and 1.53, 5.37 and 5.43 at Gurdaspur was recorded at 30, 60 and 90 DAS, respectively with 9.0 t ha^{-1} mulch application which was significantly higher than 6.25 t ha^{-1} and no mulch treatments. Leaf chlorophyll content index values and PAR interception (%) were significantly higher under straw mulch application than no mulch during all the crop growth stages. Paddy straw mulch at 9.0 t ha^{-1} reduced the soil temperature by 0.7 to 4.6 and 0.4 to 3.7 ^{0}C at Ludhiana and 1.2 to 3.8 and 0.4 to 2.2^{0}C at Gurdaspur at 5 and 10 cm soil depth, respectively as compared to no mulch treatment at different time intervals. Straw mulch treatments did not significantly affect the number of days taken to emergence, but tasselling, silking and physiological maturity stage was enhanced by 2.2 to 2.4, 1.4 to 1.7 and 0.6 to 0.8 days, respectively at Ludhiana and 1.0 to 1.8, 1.1 to 1.6 and 0.7 to 1.1 days at Gurdaspur under both straw mulch treatments as compared to no mulch. Both 6.25 and 9.0 t ha^{-1} mulch treatments produced comparatively more number of cobs per plant as compared to no mulch treatment. Yield attributing characters and yield were highest with the 9.0 t ha^{-1} mulch application which was significantly higher than 6.25 t ha^{-1} and no mulch treatments at both the locations. Straw mulch treatments also resulted in significantly higher harvest index as compared to no mulch treatment. Different mulch treatments did not significantly influence the shelling percentage, protein and oil content. Maximum gross returns, net returns and benefit cost ratio were obtained under 9.0 t ha^{-1} mulch application which was significantly better than 6.25 t ha^{-1} and no mulch treatments.

Weed control

At 20 DAS, atrazine application at 1.0 kg ha^{-1} effectively controlled weed density and dry matter accumulation of grasses, broadleaf weeds and sedges in comparison with atrazine application at 0.8 kg ha^{-1} and unweeded check. At 40 DAS, tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} were found very effective in controlling different species of weeds as compared to both doses of atrazine. Application of tembotrione at 0.110 and 0.088 kg ha^{-1} gave significantly better control of *D. aegyptium, E. tenella, D. sanguinalis*, *A. racemosa, E. colona, D. arvensis, C. rotundus* and *C. compressus* at Ludhiana and *D. aegyptium, C. dactylon, A. philoxeroides, P. niruri* and *C. rotundus* at Gurdaspur in comparison with atrazine at both doses. Similarly, application of atrazine at 1.0 kg ha^{-1} also effectively controlled the *E. indica, C. benghalensis, E. crusgalli, T. portulacastrum* and *M. nudicaulis* at Ludhiana and *E. indica, C. benghalensis, T. portulacastrum, D. arvensis* and *E. hirta* at Gurdaspur. Both doses of tembotrione recorded significantly less density and DMA of weeds in comparison with atrazine at both doses (1.0 and 0.8 kg ha^{-1}) and unweeded check. Highest weed control efficiency of 96.2 & 96.4 % and 96.2 & 96.3% was recorded with tembotrione at 0.088 and 0.110 kg ha^{-1}, respectively at Ludhiana and Gurdaspur. Lower values of weed index were recorded under tembotrione at 0.088 and 0.110 kg ha^{-1} in comparison to other herbicide treatments and unweeded check.

Plant stand was not significantly influenced by different weed control treatments, but the plant height was significantly influenced by different weed control treatments. The data showed that at both locations of Ludhiana and Gurdaspur at 90 DAS, maximum height, leaves, DMA, LAI, chlorophyll content and PAR interception was recorded under both doses of tembotrione in comparison to other herbicide treatments and unweeded check. Number of days taken to emergence was not significantly influenced by different weed control treatments. Among herbicide treatments, tembotrione at both doses took less number of days to tasselling, silking and physiological maturity in comparison to other herbicide treatments and unweeded check. Yield attributing characters, grain and stover yield and harvest index were highest under weed free treatment which was statistically at par with both doses of tembotrione but significantly higher than atrazine at 1.0 kg ha^{-1}, atrazine at 0.8 kg ha^{-1} and unweeded check at both the locations. Different weed control treatments did not significantly influence the cobs per plant, shelling percentage, protein and oil content. Maximum gross returns were recorded under weed free treatment which was statistically at par with both doses of tembotrione but were significantly higher than other herbicide treatments and unweeded check. However, both doses of tembotrione recorded statistically similar but significantly higher net returns and B: C in comparison to weed free, atrazine at both doses and unweeded check.

Interaction of straw mulch and weed control

The interaction between straw mulch and weed control treatments with respect to weed density was significant at 40 DAS which showed that, in comparison to all herbicide-mulch combinations, lowest density of *D. aegyptium, E. tenella, D.sanguinalis, E. colona, C. dactylon, T. portulacastrum, C. rotundus* and *C. compressus* was recorded with the application of tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} each in combination with 9.0 t ha^{-1} mulch. Similarly, total density and DMA of weeds was significantly less under tembotrione at both doses (0.110 and 0.088 kg ha^{-1}) each in combination with 9.0 t ha^{-1} mulch as compared to all other treatment combinations. Lower dose of tembotrione (0.088 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch resulted in significantly lowest total density and DMA of weeds than tembotrione at 0.110 kg ha^{-1} without mulch. Lower dose of atrazine (0.8 kg ha^{-1}) in combination with 9.0 t ha^{-1} mulch recorded significantly lowest total density and DMA of weeds as obtained under its higher dose (1.0 kg ha^{-1}) without mulch. Thus, the data indicated that 9.0 t ha^{-1} mulch application was more effective and helped in reduction of 20 % herbicide dose both in atrazine and tembotrione for controlling the density and total DMA of weeds in maize.

Grain yield and gross returns under tembotrione at both doses (0.110 and 0.088 kg ha^{-1}) and weed free treatment in combination with paddy straw mulch at 9.0 t ha^{-1} were significantly higher as compared to all other treatment combinations at both the locations. These treatments were followed by tembotrione at both doses and weed free treatment each in combination with 6.25 t ha^{-1} mulch. Lower dose of atrazine (0.8 kg ha^{-1}) in combination with 6.25 t ha^{-1} mulch produced statistically similar grain yield as obtained under its higher dose

(1.0 kg ha^{-1}) without mulch. Application of 9.0 t ha^{-1} mulch without any herbicide (unweeded check) produced statistically similar yield as obtained with atrazine at higher dose without mulch, thus indicating the beneficial effect of straw mulch. Under no mulch conditions, tembotrione at higher dose produced significantly higher grain yield of maize as compared to its lower dose but tembotrione at lower dose in combination with 6.25 t ha^{-1} mulch resulted in significantly higher grain yield than its higher dose without mulch. Tembotrione at both doses in combination with 9.0 t ha^{-1} mulch application recorded higher net returns and B:C in comparison to all other herbicide-mulch combinations due to higher grain and stover yield. Thus, the results indicated that mulch application helped in reduction of 20% dose of tembotrione besides improving in the grain yield of maize.

Conclusion

- Application of paddy straw mulch at 9.0 t ha^{-1} recorded significantly less weed density and DMA of grasses, broadleaf weeds and sedges as compared to paddy straw mulch at 6.25 t ha^{-1} and no mulch treatments. Among the herbicide treatments, tembotrione at 0.088 kg ha^{-1} and tembotrione at 0.110 kg ha^{-1} were found very effective in controlling different weed species in maize as compared to atrazine at 0.8 kg ha^{-1} and atrazine at 1.0 kg ha^{-1}.
- Yield attributing characters, grain yield, net returns and B:C were highest with 9.0 t ha^{-1} mulch application which were significantly higher than 6.25 t ha^{-1} and no mulch treatments. Application of tembotrione at 0.088 and 0.110 kg ha^{-1} each in combination with paddy straw mulch at 9.0 t ha^{-1} resulted in significantly more yield attributing characters, grain yield, net returns and B:C in comparison to all other herbicide-mulch combinations.

So, it can be concluded that for getting higher productivity and profitability from maize, tembotrione at 0.088 kg ha^{-1} as post-emergence in combination with paddy straw mulch at 9.0 t ha^{-1} can be applied, as this herbicide-mulch combination helps in reduction of 20% dose of herbicide.

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APPENDIX I

Weekly meteorological data recorded at Ludhiana during the crop season

Meteorological Week	Average air temperature (°C)			Average relative humidity (%)			Weekly rainfall (mm)	Sunshine hours per day	Weekly evaporation (mm)
	Max.	Min.	Mean	Morning	Evening	Mean			
25	34.5	25.5	30.0	75.0	53.0	64.0	18.8	9.0	41.8
26	33.7	27.4	30.6	75.0	61.0	68.0	77.2	6.1	39.2
27	35.4	25.7	30.6	80.0	59.0	69.5	39.6	7.8	42.8
28	35.1	28.3	31.7	74.0	59.0	66.5	9.8	7.0	41.0
29	34.5	28.5	31.5	79.0	61.0	70.0	25.0	6.3	34.6
30	34.1	27.7	30.9	79.0	62.0	70.5	37.4	7.2	42.4
31	32.6	27.2	29.9	85.0	72.0	78.5	20.6	3.6	26.6
32	35.0	28.0	31.5	82.0	66.0	74.0	0.0	5.3	31.2
33	35.0	27.6	31.3	80.0	61.0	70.5	15.0	9.0	37.0
34	33.3	25.8	29.6	85.0	65.0	75.0	11.6	5.6	27.6
35	32.0	25.7	28.9	84.0	74.0	79.0	100.0	6.1	26.4
36	33.7	24.7	29.2	81.0	61.0	71.0	2.4	9.5	30.9
37	33.9	24.5	29.2	85.0	55.0	70.0	0.0	7.9	30.0
38	33.9	23.1	28.5	85.0	49.0	67.0	7.4	6.7	30.4
39	34.6	23.3	29.0	88.0	49.0	68.5	0.0	9.0	27.6

Source: Meteorological observatory, PAU Ludhiana.

APPENDIX II

Weekly meteorological data recorded at Gurdaspur during the crop season

Meteorological Week	Average air temperature (°C)			Average relative humidity (%)			Weekly rainfall (mm)	Sunshine hours per day	Weekly evaporation (mm)
	Max.	**Min.**	**Mean**	**Morning**	**Evening**	**Mean**			
23	38.2	23.8	31.0	51.0	40.0	45.5	11.1	4.2	40
24	38.3	23.0	30.7	51.0	34.0	42.5	2.9	6.9	70
25	34.0	23.4	28.7	77.0	53.0	65.0	32.4	4.9	20
26	33.0	26.2	29.6	77.0	67.0	72.0	75.3	2.9	37
27	34.2	24.6	29.4	77.0	64.0	70.5	67.8	6.9	25
28	33.4	26.0	29.7	83.0	69.0	76.0	116	3.3	52
29	32.9	25.7	29.3	83.0	72.0	77.5	75.5	4.5	34
30	33.4	26.0	29.7	84.0	70.0	77.0	101.1	5.5	31
31	31.0	24.1	27.6	94.0	72.0	83.0	132.7	0.8	09
32	33.0	25.0	29.0	87.0	76.0	81.5	29.1	2.8	19
33	32.7	25.1	28.9	84.0	75.0	79.5	1.3	2.9	43
34	31.9	24.4	28.2	85.0	75.0	80.0	20.3	5.4	32
35	31.7	25.3	28.5	82.0	75.0	78.5	26.8	4.9	39
36	32.5	23.5	28.0	85.0	71.0	78.0	23.7	6.2	54
37	32.8	23.1	27.9	85.0	67.0	76.0	0.0	7.3	59

Source: Meteorological observatory, RRS, Gurdaspur.

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- Awarded PAU Gold medal for standing first position in B.Sc. Agri. (Hons.) Programme
- Awarded S.S. Labh Singh Medal for standing first position in B.Sc. Agri. (Hons.) Programme with specialization in Agronomy
- University Merit Certificate holder for B.Sc Agri. (Hons.) Programme
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- Sardar Gurdit Singh Kang Scholarship during 2011-12 to 2013-14 & 2015-16 in B.Sc. Agri. (Hons.) Programme
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