Studying the Effects of Different Mulch Materials on Plant Growth and Soil Moisture Conservation

By

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I dedicate this thesis to my respected, beloved and humble parents for their unconditional love, endless sacrifices and continuous prayers

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List of Acronyms

Acronym	Abbreviation
FAO	Food and Agriculture Organisation
RUE	Radiation Use Efficiency
LDPE	Low Density Polyehtylene
HDPE	High Density Polyethylene
PVC	Poly Vinyl Chloride
LLDPE	Linear Low Density Polyethylene
WUE	Water Use Efficiency
UV	Ultra Voilet
IESE	Institute of Environmental Sciences and Engineering
ICT	Islamabad Capital Territory
NUST	National University of Sciences and Technology
NARC	National Agriculture Research Center

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ABSTRACT

Mulching is one of the important agronomic practices in conserving soil moisture and modifying the soil physical environment. Wheat is an important food crop in Pakistan and is sensitive to soil moisture stress. Lab scale research experiment was carried out at IESE, NUST, Islamabad, Pakistan to estimate the effects of different types of organic mulches on soil properties and growth and development of wheat. Four different types of mulches (vermicompost, farmyard manure, wheat straw and poultry litter) were used in experiment and results were compared with control (no mulch) treatment. Results depict that mulching, specially vermicompost significantly increased soil moisture retention and positively affects plant growth thus increasing spike length and plant biomass. Soil analysis showed that electrical conductivity and organic matter was increased by 59.5% and 70.2% respectively due to percolation of nutrients from mulch materials. While soil available potassium was increased by 55.46% and soil phosphorus was also increased. Plant analysis showed that plant shoot was enhanced by 1.2 times. Root length was increased by 95.5% respectively, in vermicompost treatment as compared to control. Maximum spike length was achieved in vermicompost where an increase of 1.3 times was observed as compared to control. Therefore, it was concluded that under water scarcity conditions, mulching will be beneficial for wheat crop and may contribute for better plant growth and performance especially in rainfed and dry areas.

CHAPTER 1

INTRODUCTION

1.1 Background

Food security is involved with the existence of human life. It is principally built on three stakes:

(i) food availability— sufficient quantities on a consistent basis;

(ii) food access—the ability to obtain adequate and nutritious food; and

(iii) food utilization—satisfying dietary requirements.

In the developing countries food security is being threatened because the patterns of food production are changing along the lines of global trends. Some authors rank food security as fundamental as national security (Ahmed et al, 2007). The most important and major threat to this is climate change which is responsible for poorly sustaining agriculture in these regions. Among developing countries, Asian and African countries accommodate more than 70% of the world's population that is hungry and facing food shortage. One of the important study has concluded that food security in the world is challenged by increasing food demand and threatened by declining water availability.

Globally, around 40% of food is produced by irrigated agriculture which consumes around 69% of fresh water resources for this purpose (FAO, 2000). According to some conservative estimates, increase in global population will result increase in annual demand for food crops like rice and wheat by 1.27% between 2000 and 2025.This is creating pressure on agriculture sector to decrease its demand for freshwater, in arid and semi arid areas of world in general and Asian and African countries in particular. Similarly, high population growth and decreasing fresh water supply for urban and industrial growth are also pivotal factors.

Rain-fed areas play an important role in crop production in developing countries (Kazmi et al. 2005). Water stress is one of the most significant environmental stress in agriculture worldwide linked to reduction of yield under drought conditions. Similarly, drought and salinity are the major causes of water stress in growing plants. Drought leads to famine, which is mainly because of disruptive growth and less yield of food crops. In African countries, edible crops yield decline each year because of drought and its consequences. The average yield reported from water stress may be reduces by more than 50%.

Wheat (*Triticum aestivum* L.) is among the most important cereal crop in the world (Akbar, 2001; Zahid et al., 2011). It is one of the main source of staple food for Pakistani population (Anon., 2003). Wheat has received central attraction among staple food of Pakistan being favoured by largest proportion of Pakistani population thus got central position in agricultural policies. According to Mirbahar et al.,2010, wheat adds 12.5% value to agriculture and 2.9% to GDP of Pakistan. Pakistan is among countries that produce largest wheat in recent decades and ranked 9th in wheat production. But this yield is being affected due to varying climate patterns and recent statistics showed that the average grain yield of wheat in Pakistan is much lower than other wheat growing countries of the world i.e.2379 kg ha^{-1} (Sial et al., 2003; Malik, 2006).

Wheat crop with full watered potential has much greater yield and biomass as compared to water stress crop which causes cumulative effects on crop like reduction in leaf area, biomass and yield (Ahmed et al, 2007 and Stagnari et al., 2014). It has been reported that when drought is imposed at different stages of plant growth (tillering, booting, earing, anthesis and grain development), reduction in radiation use efficiency (RUE) was observed that led to decreased growth rate Water availability is necessary for better development during all these stages.

1.2 Mulching

Mulch is any type of material that is spread or laid over the surface of the soil as a covering. It is used to retain moisture in the soil, suppress weeds and keep the soil temperature lower. Mulches are of two types, organic and inorganic. Inorganic mulches may include plastic (shredded or sheet), gravels, ash etc. while examples of organic mulches are crop residues, paper mulch, farmyard manure, compost, wood chips, saw dust, wheat straw, etc. Organic mulches also help improve the soil's fertility, as they decompose. In addition to reducing competition from weeds, mulches are used to increase water infiltration, reduce evaporation, modify soil temperature and increase crop yields (Allison et al., 2004). Earlier researches have revealed that the use of organic mulches helps in improving crop production through moisture conservation (Baig and Asghar., 2016). Incorporation of organic matter has been reported to augment water retention capacity by improving the structure and physical environment of soil. Improvements in yield of various crops including yam (*Dioscorea rotundata poir*) (Sophie R., 2009), wheat (*Triticum aestivum. L*) (Chakraborty et al. 2008), groundnut (*Arachis hypogaea L.)* and cassava (*Manihot esculenta crantz*) has been reported by Oparanadi et al., (2007). Mulching was also found beneficial for pest control. It enhances the suitability of crop to compete for nutrients by increasing defence against pest. Mulching also supress weeds growth by creating a physical barrier to sunlight thus work as a photosynthetic inhibitor for weeds. Hand weeding and pesticides use also decrease by use of mulch material. (Brown et al., 2014).

1.3 Organic Mulches

Organic mulch can be grown in situ like residues of old crop left as it is on soil surface, crop cover or living mulch like grass, or legume mulch. It may also be grown or produced ex situ and brought in for field application, e.g., straw, sawdust, plastic products etc.

Organic mulches like vermicompost, farmyard manure, poultry litter and straw mulch have been selected for this study on the basis of their local availability, better performance and easy application.

1.4 Significance of Study

Rain fed areas are facing water stress mainly due to less availability of freshwater resources and the occasional appearance of dry spell. Situation gets worsened in case of a drought thus there is a need of adapting techniques that can combat such conditions. Organic mulches have been tested on wheat crop to study their moisture and nutrients enhancement potential in order to help farmers in achieving better crop yields in the periods of droughts.

1.5 Objectives of Study

Objectives of the study were;

- To study the effects of organic mulches on soil physical properties
- To study the effects of mulches on plant growth

CHAPTER **2**

LITERATURE REVIEW

2.1 Mulch and Mulching

Mulching is an old agronomic practice which involves use of organic and inorganic materials over soil surface. The term 'mulch' is derived from German word 'molsch' which mean soft or decaying materials. The word mulch is apparently referred to the use of straw and leaves by gardeners as a spread over the ground as mulch (Pavlu et al., 2016). Since mulch materials were mostly organic and natural (like straw and dry leaves) as used by farmers and gardeners in old times, so this term evolved. (Jacks et al., 1955). There are various benefits of mulches but most significant are the soil water conservation and erosion control, particularly in arid and semi arid areas. Other benefits of mulching include modification of soil temperature, weed control, soil conservation and addition of organic material after decomposition, improvement in soil structure, yield and crop quality enhancement. Mulch proves to be helpful in protecting roots from extreme heat and cold. It provides optimum conditions for root and plant growth by covering the soil (Dilip Kumar et al., 1990). This includes temperature moderation, reduction in salinity and weed control. Mulching are convenient to apply at orchards, gardens as well as in crop fields. Mulching not only reduce soil deterioration through runoff prevention but also by controlling soil loss prevention. It also minimizes weed infestation thus, it helps in soil moisture conservation and control soil temperature fluctuations (Nyagumbo et al., 2015). All this results in improvement in soil physical, chemical and biological properties and nutrient addition in soil to enhance plant growth. Therefore mulching effects can be divided in two categories, i.e. effects on soil and effects on plant growth and crop yield. Detailed review of literature has been conducted by Bhardwaj (2013) on use of mulches and he concluded that it is very useful in protecting the roots of the plants from heat, cold. Mulch can be used to cover soil surface around the plants which in return creates congenial condition for the growth including temperature moderation, reduce salinity and weed control. It also exerts positive effects on earliness, yield and quality of the crop (Qanstan et al., 2004). Both black and clear plastics are used as mulches in agriculture. In nutshell, mulching can be effective in increasing horticultural crop production in water scarcity regions.

2.2 Types of Mulches

There are generally two types of mulches: organic and inorganic

2.2.1 Organic mulches

Organic mulches are those materials which are derived from living beings i.e. plants and animals such as saw dust, straw, hay, leaf, peanut hulls, compost, wood chips, wood shavings, animal manures etc. It is recommended in literature that mulch should be applied just after seed germination to get optimum advantages of from the organic mulch (Bhardwaj., R. L., 2013). Different rates of mulch applications are presented in literature according to need and nature of soil. Advantages of organic mulches includes reduction in leaching of nitrates, improvement in soil physical properties, reduction in erosion, organic matter enhancement, water conservation and temperature regulation, increase rate of nutrient cycle as part of biological activity (Muhammad et al., 2009; Sarolia and Bhardwaj, 2012). One of the prominent problem during the applications of natural materials is that it requires extensive human labour and cannot be easily spread on soil surface. (Baque et al, 2006).

2.2.2 Inorganic mulches

Mulches that are derived from inorganic sources are termed as inorganic mulches examples are: plastic mulch, gravel, ash etc. Plastic mulch is one of the most used commercial mulch (Zhao et al., 2016). Mostly poly vinyl chloride and polyethylene films are used for mulching purposes. It can increase temperature around plants during night time in winter due to its high permeability to long wave radiations. Therefore, polyethylene mulch is used mainly in production of horticultural crops (Bhardwaj et al., 2011). Based on different types of polymers, a varied number of plastic mulches were evaluated on basis of polymers during 1960 (Chung and H.D., 1987). All kinds of plastics like LDPE, HDPE, and flexible PVC were used and it was observed that majority of plastic mulches are beneficial with minor difference in their performances. Mostly LLDPE is in use nowadays, being cheaper. Application of black plastic mulch is becoming popular nowadays in arid and semi arid regions and very good results were observed with its use. Control of weeds is also a benefit of black polyethylene under organic system of crop production as reported by Arora et al., 2002.

2.3 Effects of Mulching

Overall, mulch is a helpful and nourishing material that helps in growth of plant and retention of soil health. Researchers have done various experiments to explore the benefits of mulch and divided them in following categories:

1) Effects of mulching on soil

2) Effects of mulching on plant

3) Effects of mulching on insect pests and micro flora

2.3.1 Effects of mulching on soil

Effect of mulching materials on soil can be observed in various forms as following:

2.3.1.1 Effect on soil moisture conservation

Mulching modify favourable soil micro-climatic conditions thus conserve soil moisture. Mulch thickness also matters while conserving soil moisture at considerable range (Wang et al., 2014). Soil surface that is covered with mulch shows less weed growth as well as infiltration of rain water is high during growing season thus increase moisture retention (Robert, T., 2008 ; Jun et al., 2014). Inorganic mulches like plastic helps in shedding excessive water away from the crop root zone in high rainfall areas (Li et al., 2014). Irrigation frequency and amount of used water also decreased and it helps in reduction of physiological disorders related to soil moisture like blossom end rot in tomato, fruit deterioration in lime and pomegranate. Similarly, Chen and Katan (1980) has observed that plastic mulch increase soil water content in upper layer i.e. top 5 cm of soil (an increase of 4.7 per cent in clayey, 3.1 per cent in loamy and 0.8–1.8 per cent in sandy soil). Das et al., 1990 stated that use of polyethylene mulch field, augmented the temperature of soil specially in early days of spring, reduced weed growth, enhanced soil moisture conservation, reduced pests insect population, advanced crop yield and efficient soil nutrient use. Mulch acts as a vapour barrier between sun and soil by creating a shade thus slows down moisture loss from soil regime. Rodrigues et al. (1999) used black polythene sheet (0.18 mm thick) as mulch and observed that higher water use efficiency (WUE) was caused by lower evaporation in Rosa indica. Thakur et al. (2000) observed that use of mulches such as grass, plastic, vetiver grass increased growth of bell pepper (*C. annuum cv*. California Wonder) up to 25 to 75 per cent in water deficient environment while higher water use efficiency (WUE) was recorded in plastic mulch. Crop residue mulch reduced soil water evaporation up to 34-50 percent (Hatfield et al.,2001). Same results was stated by Khurshid et al. (2006) and Muhammad et al. (2009) that mulching improves the natural environment of the soil and it avoids decrease in soil water levels.

2.3.1.2 Effect on water infiltration

Mulches when spread over soil act as interface between soil-atmosphere interface which has a direct influence on infiltration of rainwater and evaporation (li et al., 2013). Mulch cover reduces surface runoff and holds rainwater at the soil surface thereby giving it more time to infiltrate into the soil (Khurshid et al., 2006). Putting layer of mulch on soil surface reduced amount of irrigation water required by the pepper and onion crop reduced by about 14 % to 29 % and 70 % respectively (Abu-Awwad.,1999 and Siczek et al., 2015).

2.3.1.3 Effect on overall soil environment

Soil physical conditions, biological activities and chemical environment improve by mulching. Changes in soil hydrothermal regime changes due to mulching causes improvement in soil physical environment like increase soil aggregate stability, hindrance of erosion and soil loss. Soil organic matter enriches with use of organic mulches and also improves soil biological environment and biological activities.

2.3.1.4 Effect on soil temperature

Organic mulching help to reduce soil temperature in summer, increases it in winter thus prevents from extreme weather. Each mulching material have different capacity of reflecting and transmitting solar energy to soil surface. Soil temperature decreases with use of white mulches while clear plastic mulch increases temperature. Use of plastic mulch causes an increases in temperature by 0.9 to 4.3ºC at early seedling stages, 1.6 to 2.3ºC at budding stage while 0.8 to

1.9ºC in flowering phase. Studies revealed that soil temperature increases by 2.9–3.30 ºC with use of photodegradable and transparent plastic mulch (Duhr and Dubas., 1990). Soil temperature increase of 2-3 ºC was observed during winter time by using wheat straw mulch (Sarolia and Bhardwaj., 2012). Zhao et al (2016) observed that soil temperature can be higher up to 7 ºC by using clear plastic mulch as compared to bare soil. Previously, Park et al. (1996) reported an increase of 2.4 ºC in soil temperature at a depth of 15 cm by using transparent plastic film and an increase of 0.8 ºC under black plastic mulch. At night, long wave radiation emitted by the soil absorbs by the underside of the mulch resulted in slowing down cooling of the soil (Lamont, 1993).

2. 3.1.5 Effect on soil aeration

Organic mulches like crop residue helps in soil aeration by helping in free exchange of gases in between soil and atmosphere. This is facilitated by improvement of structural stability, total porosity and macro porosity, decrease of surface crusting and by improving the overall soil drainage (Pavlu et al., 2016). Mulched soil has high oxygen diffusion rate as compared to un mulched ones. The composition of gases in air under the mulch depends upon different factors like mulch C:N ratio, soil moisture regime, rate of mulch decomposition, and climatic conditions. High levels of carbon dioxide (CO_2) builds up under plastic mulch since it is impermeable to CO_2.It comes through the holes under the plastic, captured there and creates a 'chimney effect'. Since CO_2 is important for photosynthesis, abundant supply helps in growth of leaves and thus increases plant biomass during growth periods (Greenough et al., 1990) .

2.3.1.6 Effect on fertilizer leaching

Fertilizer loss due to leaching is reduced during extreme rainfall as mulch acts as shed over the drained root zone. This actions helps in putting more fertilizer before crop growing or plantation.

It was reported by Hassan et al. (1994) that N, P and K concentration increased with use of coconut mulch. Faster growth of plants, early fruit production, reduced P, increased N content in leaves and fruit was observed by Vos and Sumarni (1997). They also reported increased K concentration with the use of rice straw and decreased P concentration without mulch in bell pepper. Mulched pots showed significantly high uptake of nutrients in tomato as well as concentration of nitrogen and phosphorus was also high (Hundal et al., 2000). Worthington (2001) has stated that available nitrogen was increased with application of vetch mulch, as a result of symbiotic relationship between mulch and nitrogen fixing bacteria. Mulching keeps soil surface safe from unfavourable factors like nutrient leaching and provides favourable growing conditions for vegetables (Kolota and Adamczewska, 2004). According to Acharya and Sharma (1994) plots mulched with organic materials shows greater uptake of nutrients like nitrogen, phosphorus and potassium as compared to un mulched plots.

2.3.1.7 Addition of organic matter

Organic mulches decomposes slowly and keep adding organic matter and nutrients in soil, thus improves chemical, biological and physical properties of soil which helps increase in the crop yield. Soil conditions under mulch turns quickly favourable for root penetrations. Organic mulches conserve soil moisture but they specifically adds organic matter and increases soil nutrients (Qian et al., 2015). Soil bulk density also decreases under mulch application as reported by Lal et al. (1996) by using straw mulch (1.42 g cm^{-3}) as compared to un mulched soil (1.50 g cm^{-3}). Organic matter increases with increase in mulch material up to an optimum level (Khurshid et al., 2006). Shashidhar et al. (2009) observed that sun hemp mulch increases organic carbon content (0.71%) in soil, followed by paddy straw mulch (0.66%), whereas least organic carbon content (0.48%) was recorded in un mulched plot.

2.3.2 Effects of mulching on plant

Mulches have positive effects on plant by many ways including water retention, nutrient supply, yield and biomass enhancement etc. Some of these benefits are discussed as under.

2.3.2.1 Effect on plant growth and development

Mulch application makes soil environment more favourable for plant growth that results in healthier and vigorous plants that are more resistant to diseases and pests. Root growth also flourish as a result of maintenance of optimum temperature and water content. As a result, mulched plants show more growth and are more uniform than un mulched plants (Bhardwaj et al., 2011; Sarolia and Bhardwaj 2012). Zhnag et al (2014) showed that higher shoot length obtained by using rice straw mulch due to enhanced moisture content. Reflective film mulch combined with shading treatments increased plant height and length of primary and secondary branches of flowering plants (Hassan et al., 1994). Siczek et al. (2015) observed that black LLDPE mulch gave high plant height (81.5 cm) as compared to organic mulch and un mulch (bare)soil. Kim et al. (2000) also reported the same results in Crocosmia crocosmiiflora. Improvement in spike length, rachis length and reduction in number of days needed for floret opening, was recorded with use of paddy straw mulch in gladiolus (Barman et al., 2005). Black plastic mulch was compared with other mulching treatment by Chawla (2006) and maximum plant height (70.91 cm), highest number of branches (18.54 cm) and plant spread (53.05 cm) was recorded.

2. 3.2.2 Effect on growth duration and harvest time

Since early maturity of plants depends upon maintenance of favourable temperatures during growing seasons as vegetables shows good response to mulching in terms of maturity and yield. Application of black plastic mulch applied to planting bed before planting warm the soil and faster growth, which leads to early harvesting (Tarara, 2000 and Lamont, 2005). Early flowering, less days to fruit setting and harvesting was induced in tomato crop due to organic mulches application as compared to control (Ravinderkumar and Shrivastava, 1998). Lin et al (2015) used gravel and plastic mulch for aize crop in water deficient areas and concluded that grain yield significantly increased with its use.

Polyethylene sheets applied as mulch shortened growth season of different vegetable crops and boost early harvest and yield (Goreta et al., 2005; McCann et al., 2007). Romic et al. (2003), Walters (2003) and Hutton and Hadley (2007) used polyethylene mulch and found that it is beneficial for early harvest and higher yields of watermelon, zucchini and tomoato respectively.

2.3.2.3 Effect on yield and quality of harvest

Mulch saves fruit from touching the soil, reduces fruit cracking and soil rot in most of the cases. Fruits are rich in taste ,smoother and tender in appearance as compared to bare soil (Zheng et al., 2009). Properly installed plastic mulches protects from splashing of soil over plants during rainfall, which can reduce grading time. Use of chopped straw mulch gives higher yield while water use efficiency (WUE) and soil water content was also increased (Tao et al., 2015). Orozco et al. (1994) reported that mulching with 50% chopped straw had highly positive effects on maize yield and soil water conservation as compared to other mulch treatments(Tao et al., 2015). The difference is because of moisture conservation, weed control, optimum soil temperature and nutrient uptake in mulched area as compared to un mulched ones. Similar results were shared by Hassan et al. (1994) who reported that organic mulch gave higher fruit yield of bell pepper than control treatment. In a study Dixit and Majumdar (1995) used paddy straw as mulch on potato crop and concluded that yield and starch content of potato was increased by 27.9% and 18.18% respectively. Straw mulch, applied with a rate of 1.5t/h, produced higher yield of durum wheat while bare soil produced low yield on the other hand (Stagnari et al., 2014). Black LLDPE mulch was found beneficial in terms of highest number of fruit yield of tomato crop with an average yield of 12.73 t/h and average fruit weight of 31.8g than un mulched treatments (Lourduraj et al., 1996). Increased crop weight was observed with use of farmyard manure as compared to plastic mulch. This might be because of nutrients percolation in soil from manure mulch and nutrient uptake by plants (Benoit and Ceustermans, 1998). Similar results were noted by Rodrigues et al. (1999). Tahkur et al. (2000) used different mulches (grass mulch, straw mulch and lantana leaves) for capsicum annum L. under water deficient conditions. Results showed that lantana mulch gave highest results with a fruit yield of 7.34 t ha-1 over un mulched plots (3.69 t ha-1). It was also reported that yield increased was 198%, 164% and 141 % in lantana mulch, straw mulch and grass mulch respectively (Hong et al., 2001). Application of paddy straw as mulch on mulberry showed maximum leaf yield (46%) as compared to sorghum (32.4%) and black gram mulch (23.8%) over no mulch. Maximum duration of flowering and early flowering of crossandra cv. Saundrya was obtained by using black polyethylene mulch and other organic mulches (Murugan and Gopinath., 2001). Mulch materials also effects crop contents which directly effects nutritional value of crop. Postharvest analysis of potato tuber showed that around 46% less reducing sugars as compared to normal (un mulched crop) (Uppal et al., 2001).

2.3.2.4 Mulching and weeds

Mulch provide a physical barrier thus reduces chances of weed germination and nutrient uptake by weeds. Mulch physically supress weed seedling germination (Kołodziejczyk., 2015). Weed control by use of loose mulch materials such as sawdust, straw and compost materials from municipal green waste sources can protect from weed emergence (Baumann et al.,2000 and Merwin et al., 1995). Saw dust improves soil structure and supress weed growth since it cover soil better because of its micro particle structure. Thus it decreases water runoff, increases infiltration, conserve soil moisture and decreases water evaporation (Waterer, 2000). It is of sheer importance that mulches that are clear or green in colour had less effect on weed growth as compared to dark mulches like brown, black, dark blue or white combined with black (double colour mulch) (Bond and Grundy, 2001).

2.3.3 Effects of mulching on insect pests and micro flora

2.3.3.1 Insect pest control

Mulch reduced harmful insects invasion on plants as compared to bare soil. Kelly et al., (1989) used transparent polyethylene film as mulch and observed that it had a repellent effect on whiteflies population. Similarly, Nameth et al., (1986) used transparent polyethylene mulch as cover and found that it was helpful in catching aphids, reducing whitefly population and virus disease incidence. The reason is that mulch serves as a cover to reduce pests up to an extent (Farias-Larios, and Orozco-Santos.,1997) Transparent mulch decreases the chance of virus infection, caused by the aphids, since aphids are vector of virus infections among plants (Orozco et al., 1994). Transparent mulch acts a reflecting object, thus reflects high UV light, as stated by Kring and Schuster, (1992). Soil solarisation due to mulch effect is also a part of mulch benefits (Hooks et al., 2003).

2.3.3.2 Mulching and soil ecosystem

Application of mulch changes the soil structure from compact to well aerated, loose and rich soil conditions. It provides suitable temperature and uniform moisture that helps optimum conditions for growth of helpful symbiotic organisms like nitrogen fixing bacteria, earthworms, actinomycetes, fungi etc. These organisms helps in rapid breakdown of nutrients and makes them available for plants. Earthworms thrive under the mulch layer thus helps in improvement of soil conditions like aggregate stability, infiltration etc (Mukherjee et al., 1991). Mulching has positive effects on soil flora and fauna. Soil macro invertebrates rely on continuous availability of nutrients and mulch helps this to make them available. Soil biota also improves nutrient recycling process and building up of organic matter over a course of years (Brown et al., 2001; Holland., 2004). Since crop residues provide enough food for soil micro fauna, so it is quite pertinent that mulching increases breakdown of organic matter and make it accessible for vegetation growth (Saroa and Lal., 2003)..

2. 4 Economic Importance of Mulch

Most of the mulches that are being used by growers are usually locally available and are low cost. Crops grown with mulched treatments are healthier and give high yield thus increase gross return. It was reported by several researchers that use of polyethylene film as a mulch have positive effects on crop like moisture conservation, decrease nutrient leaching, pests and insects control and improvement in fruit cleanliness and yield (Decoteau, 2007; Diaz-Perez et al., 2007; Hutton and Handley, 2007). These effects lead to net increase in profit as reported by Sutagundi (2000). He reported that use of straw mulch gave high profits in the form of benefit cost ration of 1.80:1 in case of Chilli crop grown in India (Nagalakshmi et al., 2002). Mean value of increase in yield was reported in the range of 9.0 – 85 % depending on crops ranging from fodder, vegetables and fruit trees (Gangawar et al., 2000).

2.5 Limitations of Mulch Applications

Although mulches have been considered beneficial for crops, soil and yield, there are certainly few disadvantages depending upon nature, areas and climate as reported by Acharya et al (2005) in a detailed review article. He has described following limitations which must be taken in to account while applying mulch in the field, which are:

1. Mulch application before sowing of seeds disturbs many post sowing functions like watering of soil, application of fertilizers etc. Mulching can cause special problems for farmers since tools for tillage can blocked with mulch, thus pre sowing application of mulch is not always successful
2. In potato fields, greater percentage of stolon can become aerial shoots and more tubers can sun burned if mulching is improperly managed. Disease and pest infestation can prevail if mulch layer in potato fields do not removed after full canopy is achieved.
3. Thick mulching can lead to water logging conditions in areas of high rain fall because of water retention in soil. This can lead to disease infestation in crop. Denitrifying bacteria can thrive in soil with high water content which may cause loss of nitrogen.
4. Mulch application rate and depth decides it effectiveness. Too much thick mulch layer can hinders seedling appearance, acting as a physical barrier. It is suggested by experts to use an optimum layer of mulch so not to delay seedling appearance and thickens the mulch as seedling appears.
5. Some inorganic mulches like plastic films are a threat to environment since their manufacturing and disposal involve significant environmental problems because these are not biodegradable.
6. Various crop residues used as mulch contain phytotoxic substances which can limit plant growth due to leaching or production of allopathic chemicals by microbes.
7. Crop residues (like rice or wheat straw and saw dust) are being used in developing countries for several other reasons. For example straw is being used as a source of fodder. So when

there is scarcity of fodder, farmers do not inclined to use straw as mulch. In tropical areas, crop residues are used as roofing, fencing and also as household fuel.

8. The crop residue mulches reduce the temperature of the surface soil layers. In cool climates, this reduction in soil temperature shortens the growing season of the arable crops, while in wet areas higher soil moisture may induce gleying and anaerobic conditions. The limiting problem of using residue mulch on soils in temperate regions is its inability to remove excess water to allow the soil to warm up in time for planting the next crop.
9. If C:N ratio of material is very high as a result of soil nitrogen fixation, the mulch material can compete with crop upon decomposition.
10. Surface dwelling pathogens and pests may find it favourable to thrive on surface residue mulch. Surface residue control water loss, controls temperature extremes and offers food sources to pests and it can increase their infestation. Plant pathogens not only used this resource as food but they can reproduce in it too (Erenstein., 2000). A number of root infecting organisms survive upon crop residues. Example of such case is a root diseases caused by Pythium species that is favoured by wet soils and cool temperatures.

CHAPTER 3

MATERIALS AND METHODS

3.1 Phases of Experiment

This chapter reveals the procedure and experiments performed of the present study. Whole procedure is shown in the below flow Chart.

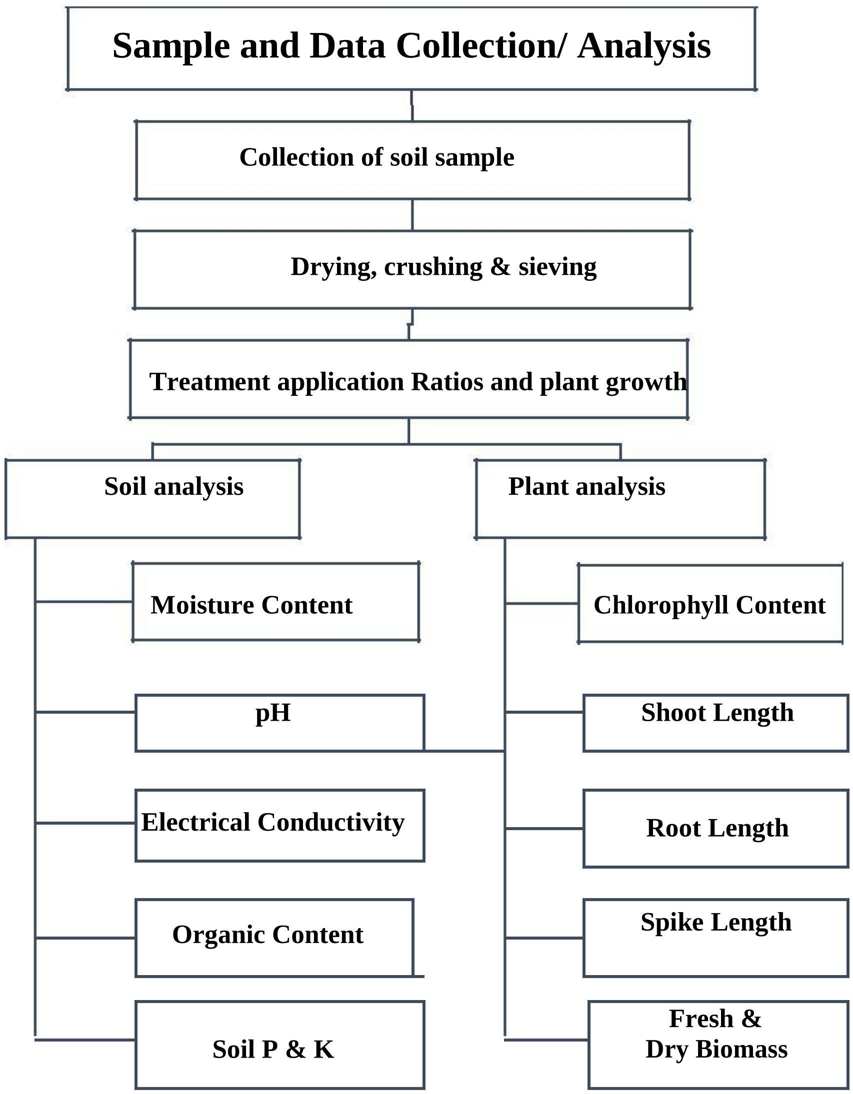


Figure 3.1: Schematic research plan

3.2 Soil Sampling Area and Experimental Setup

Lab scale experiment was conducted on wheat (*Triticum aestivum*) in the glass house situated next to IESE, premises of National University of Sciences and Technology (NUST), Sector H-12, Islamabad, Pakistan. This site is located in Islamabad Capital Territory (ICT) situated at 33.43°N and 73.04°E at the northern edge of the Pothohar Plateau in the foot hills of the Margallah. Figure 3.1 showed soil sampling and screening process.

Figure 3.2: Photograph showing steps of soil preparation

3.3 Selection of Crop Variety

For this study wheat variety Faisalabad-06 was selected on behalf of its excellent properties. This variety is high yielding and possesses durable resistance against rust and diseases. Moreover, it is suitable for early to normal planting with better performance in all types of soils.

3.4 Preliminary Soil Screening and Preparation

Soil sample was obtained from premises of National University of Sciences and Technology (NUST), Islamabad, since the it is situated in Pothohar plateau which is among arid areas of Pakistan, facing water stress on annual basis.

3.4.1 Soil classification

Classification of soil was done on the basis of saturation percentage (Malik et al., 1984).

- 0-19% Sand
- 20-29% Sandy loam
- 30-45% Loam
- 46-60% Clay Loam
- More than 60% Clayey

As per analysis our sieve and moisture content analysis, the soil sample was clay loam

3.4.2 Measurements of soil pH and EC

To ensure the suitability of soil for plant growth, pH was measured. For this purpose, 10 g of air dried soil (< 2 mm) was taken in 100 m beaker. 50 mL of distilled water was added using a graduated cylinder. The mixture was stirred well for 30 min and left to stand. After 1 h, reading was measured using a HI2211 pH/ORP meter at room temperature. Electrical conductivity was analyzed using a conductivity meter (HACH) (Janakiramn et al. 2010). Measurements have been done at room temperature.

3.4.3 Moisture content

The moisture content was measured in all samples before sowing of seed. For this purpose, firstly china dish was dried in oven for any captured moisture content in its porcelain. After drying, it was weighed. 10g air-dried soil (< 2 mm) was taken in china dish. It was dried in oven, at 105 °C for 24 hours. After 24 hours, it was removed from oven; cooled in a desiccator for 30 minutes and then re-weighed. Moisture content was calculated using the following relation: (Eaton et al., 2005).

$Moisture\ Content\ (\%) = (W1 - W2/W1)\ X100$

Where,

W1= wet weight

W2= dry weight

3.4.4 Organic matter content

Soil and mulch organic content was measured using loss on ignition method (Nikolskii, et al., 1963). China dish was heated in oven for removal of moisture from porcelain and then weighed. 10 g of sample was taken in a china dish. Sample is then placed in the muffle furnace at a temperature of 365 C. After 15 minutes, it was removed from furnace, cooled in a desiccator for 30 minutes and then re weighed.

3.4.5 Soil phosphorus and potassium

As phosphorus and potassium are major nutrients so these are measured in most of the soil laboratories for estimating the need of fertilizer for growing food crops. The modified method of Olsen et al., 1954 is a simple, quick and inexpensive soil test which is generally acknowledged as an appropriate guide of phosphorus and potassium availability, where the Ca++ precipitated as CaCO3 thus increasing the solubility of calcium phosphate. Therefore, Olsen's test has been adopted for the phosphorus and potassium analysis of soil in the Biotechnology Laboratory at IESE, NUST.

3.4.6 Reagents used

3.4.6.1 Extracting solution

For the digestion and extraction of soil and plants in order to determine chemical constituents, following solutions were used during this research.

a) Sodium Bicarbonate Solution ($NaHCO_3$), 0.5 M

42 g of sodium bicarbonate were dissolved in about 700 mL distilled water and pH was adjusted to 8.5 with 5N NaOH. The volume was made up to 1-L with distilled water.

b) Sodium Hydroxide Solution (NaOH), 5 N

50 g of sodium hydroxide were dissolved in 200 mL distilled water and made the volume up to 250 mL with distilled water.

3.4.6.2 Mixed reagent

a) 6 g of ammonium heptamolybdate $(NH_4)_6Mo_7O_{24}.4H_2O$ were dissolved in 125 mL distilled water.

b) 0.1455 g of antimony potassium tartrate ($KSbO.C_4H_4O_6$) were dissolved in 50 mL distilled water.

The dissolved reagents (a) and (b) both were added to a 1 L volumetric flask, then 500 mL of 5 N H_2SO_4 (74 mL concentrated H_2SO_4 in 500 mL DI) were added to the mixture. After mixing thoroughly, the volume was made up to 1 L with distilled water and stored in a Pyrex glass bottle in a dark and cool place.

3.4.6.3 Colour developing reagent

For this purpose, 2.64 g of Ascorbic acid (C6H8O6) were dissolved in 500 mL Mixed Reagent. Colour developing reagent must be prepared freshly as needed because it could not be kept for more than 24 hours.

3.4.6.4 Standard stock solution

Accurately, 2.5 g potassium di-hydrogen phosphate (KH2PO4) was oven dried for 1hat 105 °C, cooled in a desiccator then stored in air tight bottle. Exactly, 2.197 g potassium di-hydrogen phosphate (KH_2PO_4) was dissolved in 500 mL distilled water. This solution contained 1000 mg L-1 stock solution. Precisely, 10 mL stock solution was diluted to 100 mL final volume with distilled water. This solution contained 100 mg L^{-1} phosphorus. A series of standards were prepared from the stock solution. These solutions contained 0, 0.25, 0.5, 0.75, 1, 1.25, 1.50, 1.75, 2, 2.25, 2.50, 2.75, 3, 3.5 and 4 mg/kg phosphorus respectively.

3.4.7 Procedure

Weigh 2.5 g soil (dried with air) (< 2 mm) into a 250-mL Erlenmeyer flask; add 50 ml sodium bicarbonate extracting solution ($NaHCO_3$). The solution is then placed over mechanical shaker for 30 minutes at 180 rpm. Blank was also prepared in one flask having all chemicals except soil. Filtered the solution using Whatmann filter paper No. 42. Then 5 ml of the filtered extract was pipetted out into 25 ml volumetric flask, 5 ml color developing reagent was added into it and made the volume up to mark with distilled water. It was shaken to remove the gas bubbles. Subsequently bluish color developed. The concentration of phosphorus in soil is directly proportional to the intensity of blue color developed. After 15 minutes, the samples were analyzed on the Spectrophotometer. The absorbance of all samples (standard, blank and other samples) recorded accordingly at 880 nm wavelength. The calibration curve for standards was prepared, plotting the absorbance of the samples and phosphorus concentrations on the y-axis and x-axis respectively. From the calibration curve, phosphorus concentrations were measured for the unknown samples by following formula.

Phosphorus (mg/kg) = mg/kg P (from calibration curve) × A / Wt × 25/V... (Eq.1)

Whereas;

A = Total vol. of the extract (mL)

Wt. = Wt. of air-dried soil (g)

V = Vol. of extract used for measurement (mL)

3.4.8 Soil preparation

After selecting the suitable soil for final experiment, 50 kg soil was collected from open field at NUST, Islamabad and spread out to dry for a week with regular mixing. Prior to any further usage, the dried soil was ground manually by hand into fine particles with use of hammer and mortar. Crushed sample was sieved through a < 2mm sieve; roots, shoots and other materials were removed and fine homogenized soil was obtained. Desired amount of soil (1100 g) was weighed and subsequently added to pots. Plastic pots (purchased locally) (14cm diameter and 14 cm height) were used for the experimentation.

Soil samples in pots were watered with 330 ml of distilled water with use of beaker and pipette, until fully saturation was achieved.

3.5 Seed Collection and Sowing

Seeds of wheat variety Faisalabad-06 were collected from wheat research department at NARC. Seed samples were treated with 5% potassium hypochlorite solution and then dried. Seeds were sown in the pots after 3 days of soil saturation, when soil is ready for sowing of seeds. Seeds were applied with a ratio of ten seeds per pot. Each seed was sown 5 cm deep in soil.

3.6 Mulch Preparation and Application

Four types of organic mulches i.e. Farmyard manure, Wheat Straw, Poultry litter and Vermicompost were selected on the basis of their performance and variability. Farmyard manure was collected from local nursery located at H-8, Islamabad. Wheat straw was collected from a farm at Islamabad. Poultry manure was collected from a poultry shed located at lehtrar road, Islamabad while vermicompost was purchased from NARC, Chak Shahzad, Islamabad. All of the mulches were air dried for one week in shade. A 3cm thick layer of mulch material was applied on each replicate (McMillen., 2013).

Figure 3.3: Mulch collection and preparation

3.7 Soil Moisture Monitoring

The moisture content in each pot was measured by use of moisture meter and weighing of pots with electronic weighing on daily basis. Electronic weighing balance (model no. HX-D5) was purchased locally. Another electric moisture meter was fabricated at lab scale. Parts of moisture meter was 1) Electrodes, 2) Circuit, 3) Display screen. Electrodes sensitise moisture and displays its percentage in soil. Further, it also tells humidity and temperature in ambient environment, as shown in figure 3.3.

Electronic weighing balance works in manual way. Difference in weight/day provide mean difference which further used for percentage moisture loss/pot.

Table 3.1: Critical stages of wheat where moisture availability is necessary

Critical Growth stages	**Significance**
Tillering stage	This is the first stage in the growth of wheat plant which starts about a week after seed emergence. During this stage sufficient moisture must be available in soil. Therefore for this reason, generally first irrigation is recommended at this stage in irrigated area.
Spike and grain formation stage	This is the most critical stage in the life of wheat plant where sufficient soil moisture should be available. If moisture is not available at this stage the spike and grain formation disturbed which drastically reduced the yield.

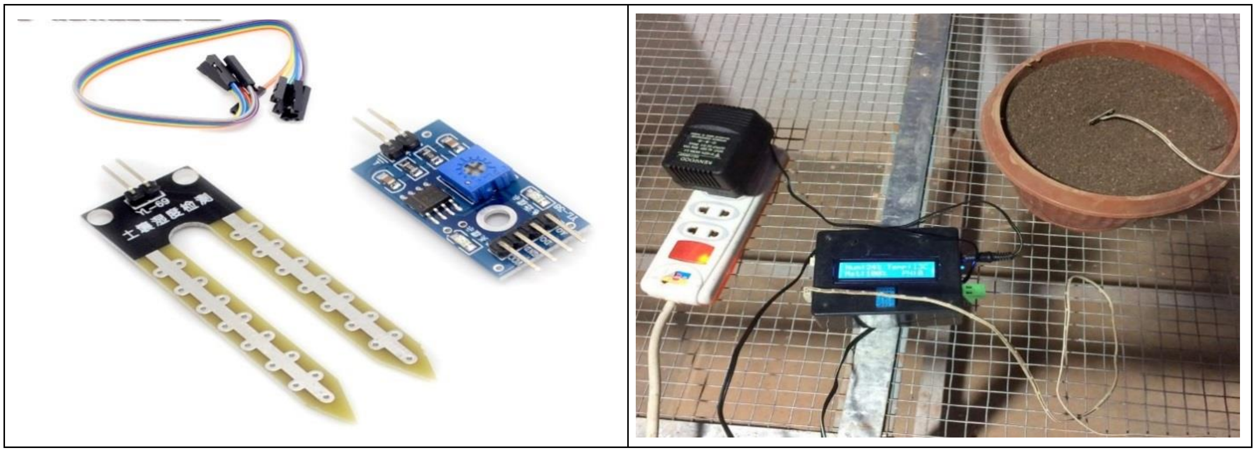


Figure 3.4: Moisture meter components and its working

3.8 Temperature Data During Study Period

Temperature data of experiment site was recorded for the study period (December 2016 –March 2017) .The minimum value of temperature recorded was 12°C in the month of January; whereas maximum value was documented in the months of March (28℃). Environmental temperature is a key parameter to change the climatic and soil conditions for crop production. Less Evaporation and normal soil temperature develop more favourable conditions for the crop growth (Zheng et al., 2009).

3.9 Plant Analysis

3.9.1 Physical parameters

Germination count

Seeds sown in each treatment were counted and compared with germinated seedlings to find the germination ratio.

Root length

At harvest, whole plant was removed from the pot and the roots were washed with distilled water. Roots of the plants were collected separately and measured with the help of measuring scale. Roots are then preserved in air tight bags for further analysis.

Shoot length

Shoot of plants of each pot was collected separately and measured with the help of scale. Shoots were then preserved in air tight bags for further analysis.

Wet and dry bio mass

Roots and shoots are weighed separately for wet and dry biomass. For wet biomass plant root and shoots are air dried and placed separately over weighing balance. For dry biomass, shoots and roots were placed in oven at 70 °C for 48 hrs. The plant material was weighed afterwards for dry biomass. Both the shoots and roots were ground with mortar pestle separately and stored in air tight sampling bags for further analysis.

3.9.2 Chlorophyll content

Leaves were sampled after 30 days of sowing for measuring chlorophyll content. It was measured after each 3 days in the whole period of growing. Chlorophyll content was measured using a portable chlorophyll content meter (CCM-200), which is defined as the ratio of percentage of transmission a 935 nm to 635 nm through leaf tissues. Calibration was done before each measurement (Richardson et al., 2002).

3.10 Statistical Analysis

The statistical analysis of results has been done using Microsoft excel and standard deviation was applied.

CHAPTER **4**

RESULTS AND DISCUSSION

4.1 Soil Parameters

Experiment analysis was done after plant harvesting and results showed that all of the organic mulches show good results as compared to control (no mulch) treatment. All of them conserve water significantly as well as soil nutrient availability also increased.

4.1.1 Initial soil analysis

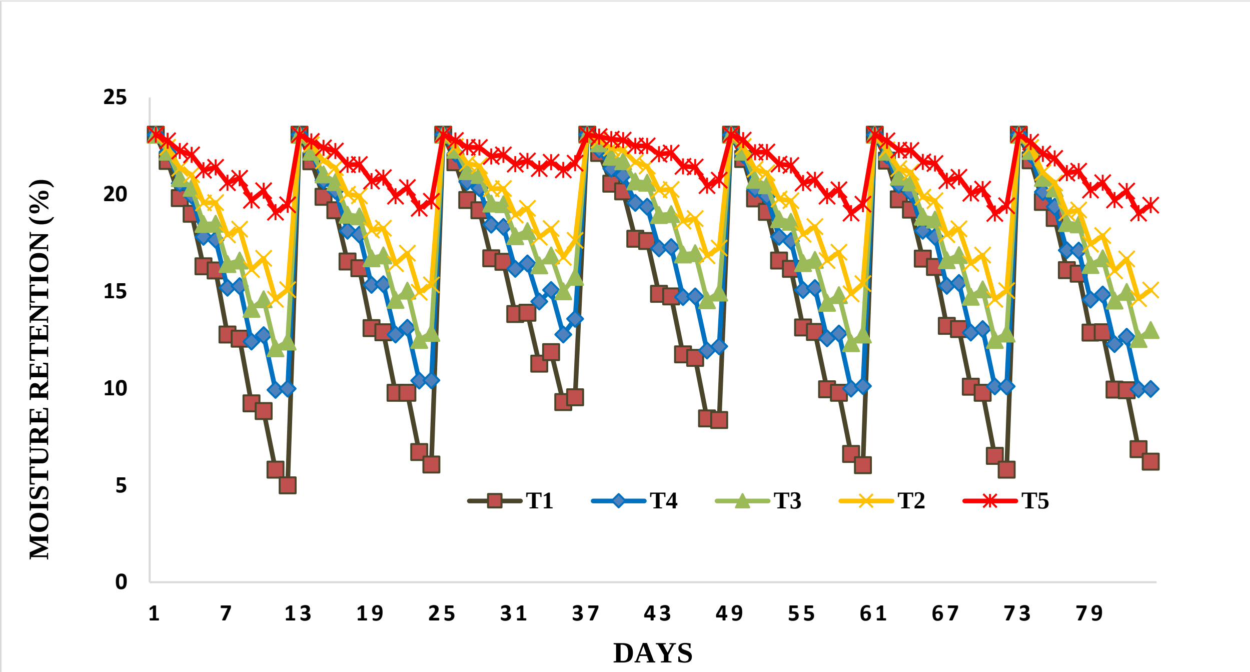
Following table depicts soil initial properties.

Table 4.1: Soil initial properties

Sr.No	Parameter	Unit	Value
1	pH	-	7.3
2	Electrical Conductivity	ds/m	0.89
3	Organic Matter Content	%age	0.74
4	Available Phosphorus	mg/Kg	1.6
5	Available Potassium	mg/Kg	141

4.1.2 Moisture content

Soil moisture content was recorded on daily basis under all four mulch treatments including one control treatment including replicates. The values varies w.r.t each treatment and temperature. It was examined that all the organic mulch treatments found effective in increasing moisture contents retention ability of soil, at varying extents.



T_{1}= Control; T_{2}= Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

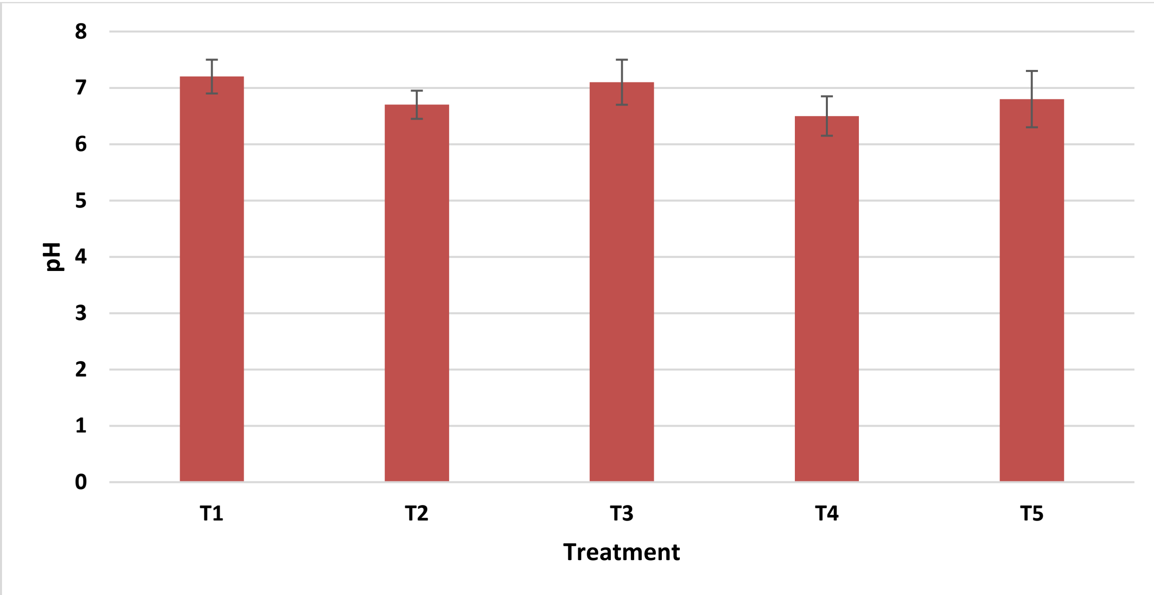
Figure 4.1: Soil moisture retention observed during the growth period for each treatment

These above shown results clearly depict that the experimental pots with vermicompost mulch showed remarkably higher moisture content values throughout the study period. Farmyard manure, straw mulch and poultry litter showed moisture retention after compost mulch respectively.

Due to mulch swathe, evaporation loss reduces from soil surfaces thus enhancing moisture content availability for wheat germination and moisture availability in root zone (A. R. Khan., 2002). Highest moisture conservation was observed in pots with compost treatment because of its compact nature. The present results are in corroboration with the findings of Kazmi et al., 2005.

4.1.2 Effect on soil pH

Soil pH of post harvest soil samples was analyzed. Figure 4.2 showed that the pH undergoes a little change in all of the mulched pots while slight decrease in pH showed in pots with poultry mulch, though it remain in neutral position. This is due to chemical nature of poultry litter which lowered soil pH. Further, Liu et al., (2010) also discussed that acidifying nature of poultry litter can lower soil pH significantly and convert in to acidic range, if use for a longer period of time.



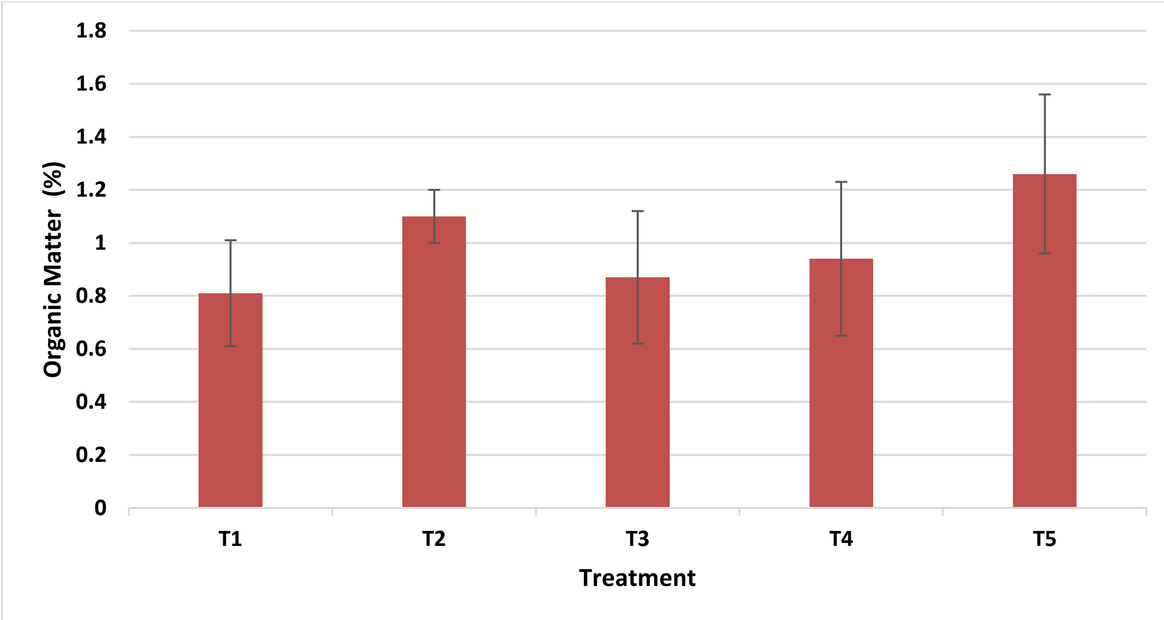
$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.2: Effect of mulch materials on soil pH values

4.1.3 Soil organic matter content

Preservation and availability of moisture contents also resulted in better crop development, compared to control treatment samples. Furthermore, organic mulch materials also contributed towards increase in organic matter in the soil. These results are in agreement with the investigations of Yang et al., 2006 and Tanner, L., 2003).

Soil organic matter content in the compost mulch and farmyard manure treatment was higher as compared to other treatment due to accumulation of the mulches in soil and due to good root growth. Shirani et al. (2002) also reported that application of mulch increased soil organic matter.

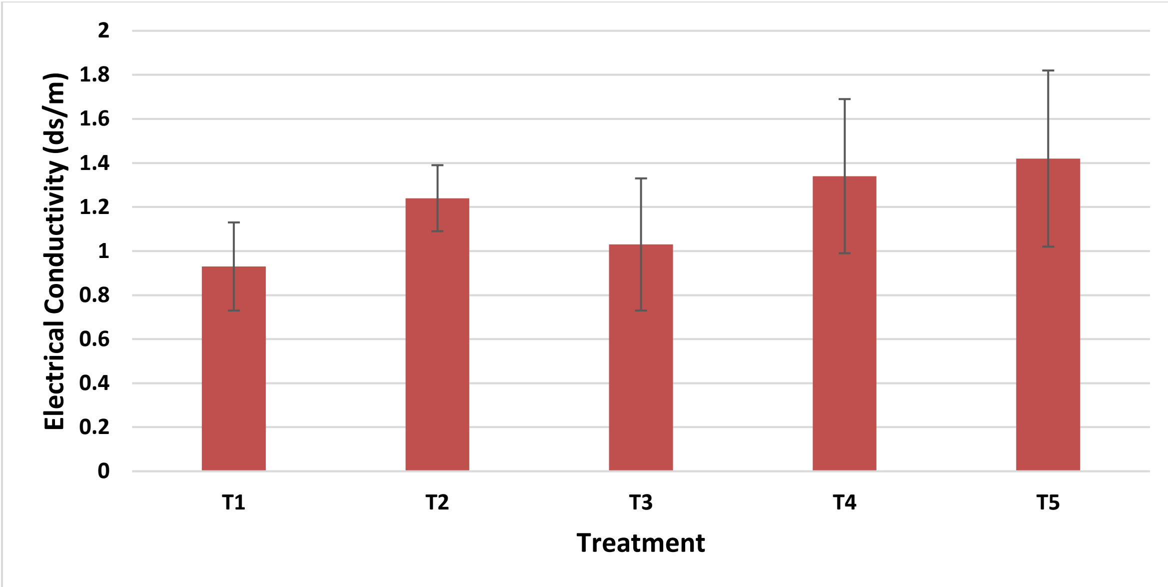


$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.3: Effect of various treatments on soil organic matter

4.1.4 Electrical conductivity

The results shown in Figure No. 4.4 expressed the effects of mulch materials on electrical conductivity of soil. The analysis of these results showed that electrical conductivity was increased slowly with different mulch materials. Electrical conductivity was highest in compost treatment while lowest in control. Permissible limits for electrical conductivity of soil is 1.0 to 10.0 dS/m or 1000-10,000 µS/cm. The electrical conductivity of all the doses falls in the permissible limits.



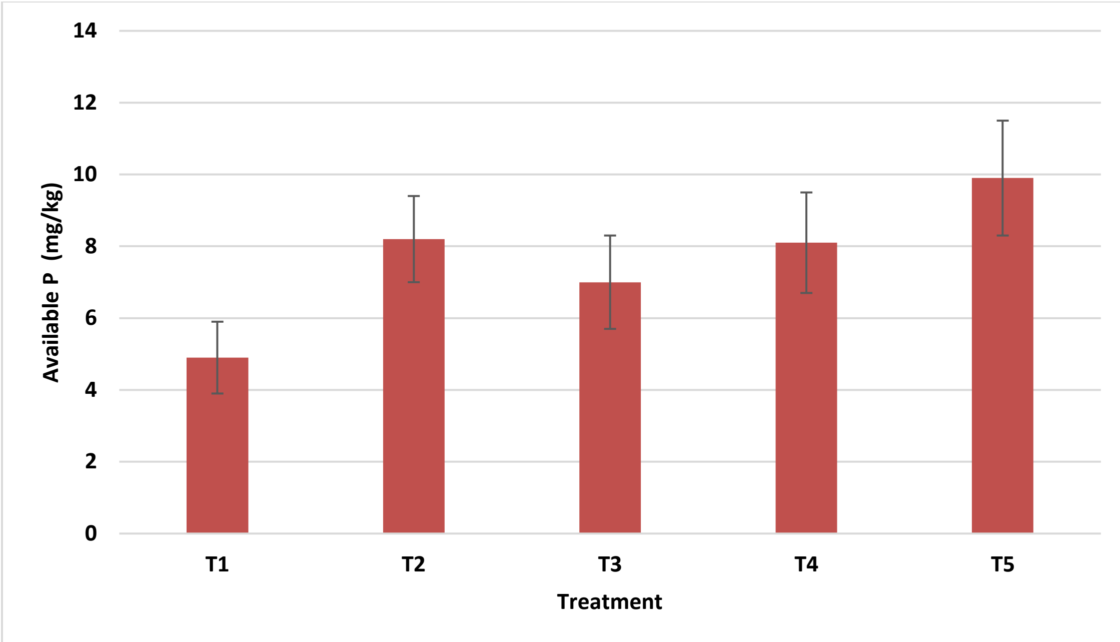
$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.4: Effect of mulch treatment on electrical conductivity values

Electrical conductivity of mulched treatments changed due to incorporation of ions in soil regime due to mulch assimilation.

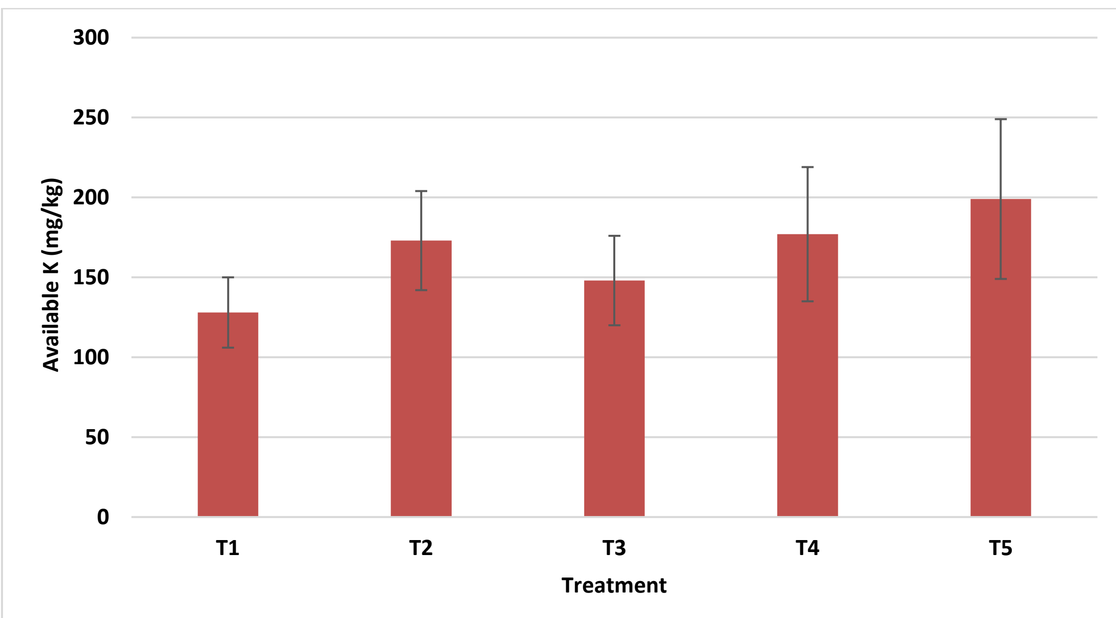
4.1.5 Soil phosphorus and potassium

NPK values of post harvest soil samples are shown in table No. 4.1. Phosphorus is used in some energy transfer compounds used for plants growth. A very important function of Phosphorus is its role in nucleic acids, the building blocks for the genetic code material in plant cells. Values were calculated in mg/kg. All treatments increased soil P & K values while reduction took place in control treatment (Gollifer., 1993).



$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.5: Effect of different mulches application on available phosphorus



$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.6: Effect of different mulches application on available potassium

Mulched pots showed a higher tendency towards available phosphorus and available potassium. Compost mulch shows high results. Similar results were observed when Sinkevičienė et al,2009 studied the effects of influence of organic mulches on soil properties and crop yield .

4.2 Plant analysis

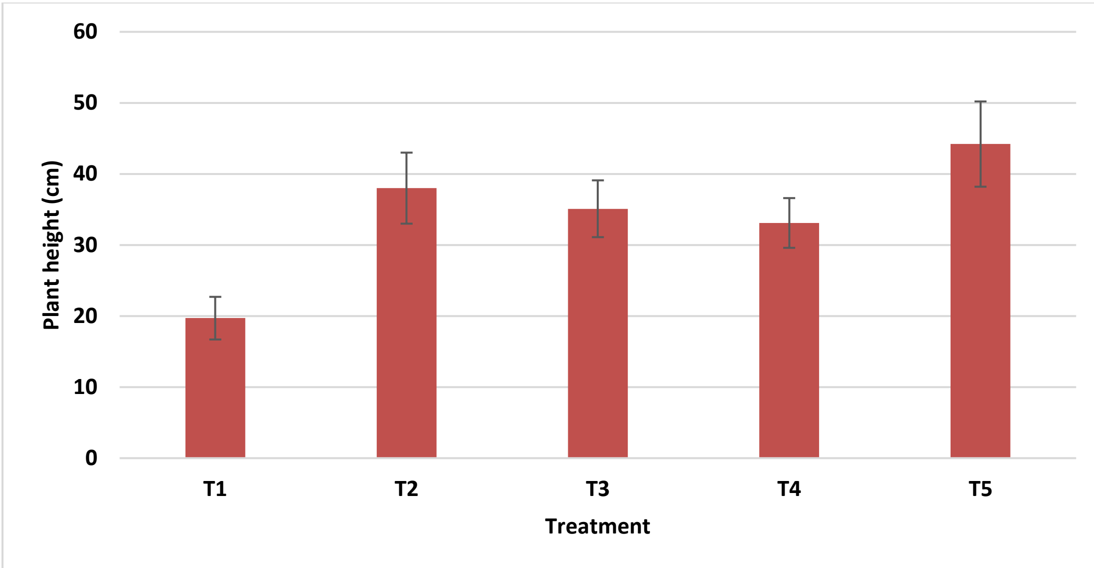
4.2.1 Germination ratio

Seed in pots with compost germinated after 4 days while rest of pots showed germination on 5th day. All the seeds sowed were germinated but due to the small size of pots, plants were thinned to four in each pot.

4.2.2 Shoot length of wheat plants

Figure No. 4.7 illustrated the shoot length of *Triticum aestivum.* Pots with compost mulch reveals better growth while in control the results were totally reversed. Significant increase in shoot length were observed in compost with 44.2 cm length , on the contrary, control showed a maximum length of 19.7cm.The bars on the figure showed the standard deviation of three replicates.

All treatments showed significant increase in plant growth except control treatment which is because of water stress and lack of nutrients availability to control treatment plants. Good shoot growth in mulched pots is mainly because of availability of nutrients and moisture conservation (Guttieri et al., 2001). Khan et al,2014 also reported an increase in *Triticum aestivum* shoot length with use of mulch materials.

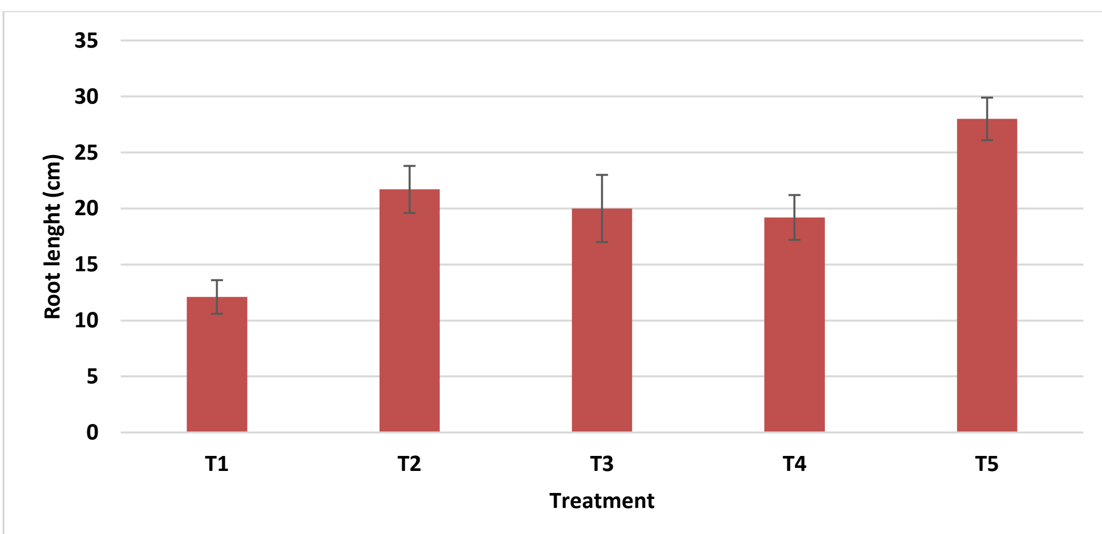


$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.7: Effect of mulches on plant shoot length

4.2.3 Root length

Figure 4.8 showed the root length of wheat plants. Compost mulch showed better results with a length of 28 cm while lowest was observed in control (12.1 cm). While Farmyard manure, wheat straw and poultry mulch showed 21.7 cm, 20 cm and 19.2 cm respectively.



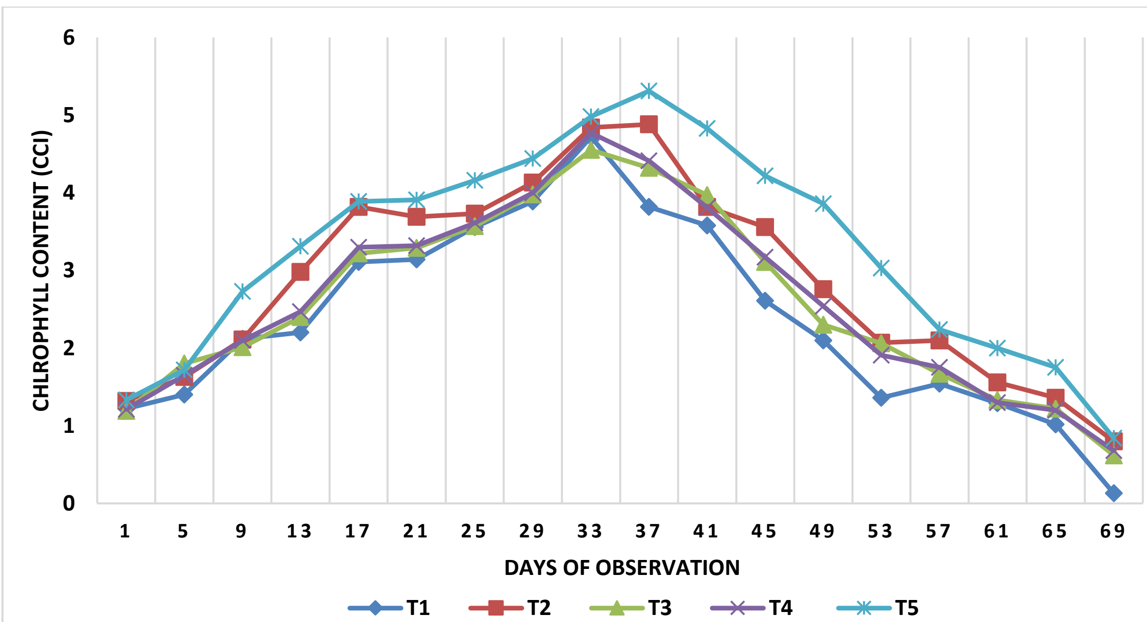
$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.8: Effect of mulches on root length of wheat

Increase in root length of compost treatment is basically because of in increased soil moisture and nutrient availability (Olasantan., 2009). While low growth in control treatment is because of acute water stress.

4.2.4 Effect on chlorophyll content (Photosynthetic pigment)

Plant photosynthetic capacity is usually reflected by leaf chlorophyll content. Chlorophyll content was measured after 30 days of plant growth after every 3 days. Figure. 4.9 showed the chlorophyll content of wheat plant at different stages of plant growth. Chlorophyll content increases with plant growth till maturation and after that phase, it declined. Highest chlorophyll content was measured in compost treatment while control treatment showed lower values.



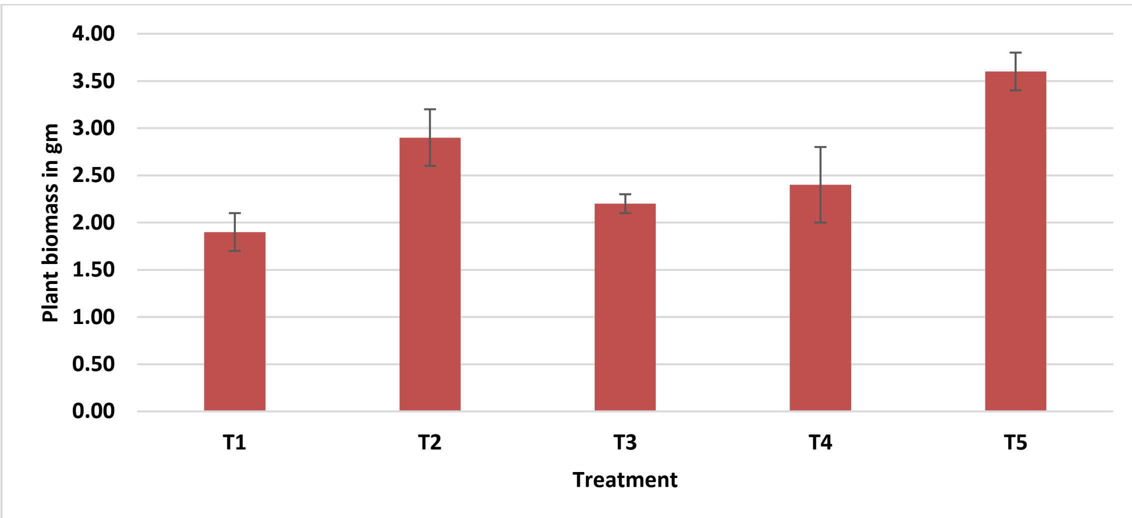
T_{1}= Control; T_{2}= Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.9: Values of chlorophyll content in wheat plants

Total chlorophyll content is correlated with fresh weight of plant which shows that chlorophyll content of plant took part in photosynthesis as a result plant grow more. Zhang et al,2014 also narrated that mulching improved root activity, soluble sugar and chlorophyll content.

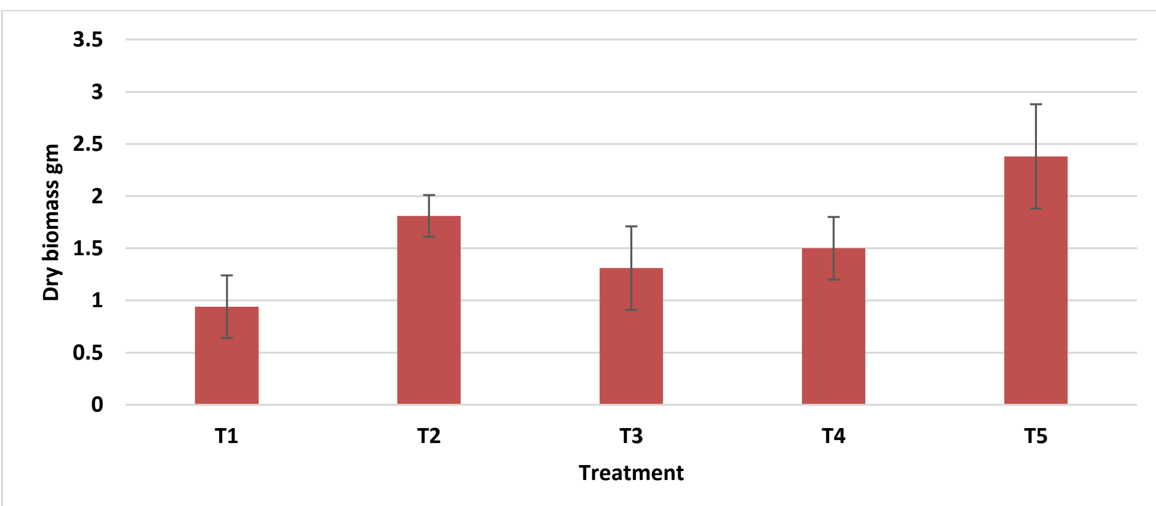
4.2.5 Fresh and dry biomass of wheat plant

Figure. 4.10 And 4.11 depicts fresh and dry biomass of wheat plants. Plants grew in compost treatment showed highest values for fresh as well as dry biomass, due to high C/N ratio of compost mulch. While plants with farmyard manure also showed good results.



$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.10. Fresh biomass of wheat plant



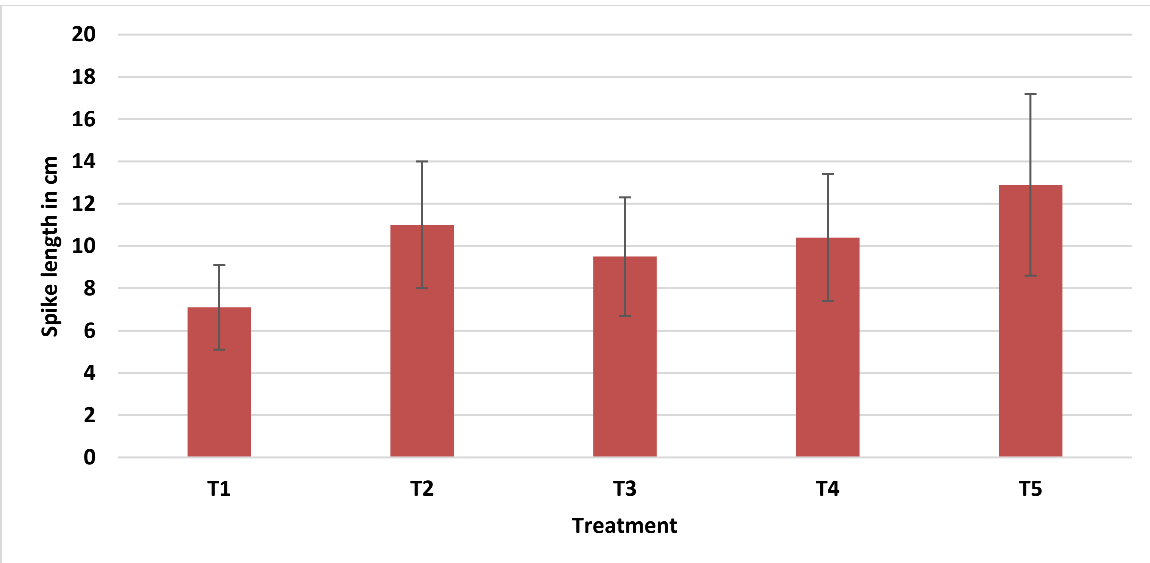
$T_{1=}$ Control; $T_{2=}$ Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.11: Dry biomass of wheat plants

Plants grown in no mulch (control) treatment show very less biomass as compared to mulched ones because of lack of nutrient availability and water stress.

4.2.6 Spike length of wheat plants

Spike length describes the grain yield and health of plant. Plants with compost treatment show spikes one day earlier as compared to other treatments. All other treatments show spikes one day later. Spike length was better in compost mulch (12.9 cm) while lowest in control treatment (7.1 cm). The results are in corroboration with Acharya and Sharma,1992.



T_{1}= Control; T_{2}= Farmyard manure; T_3= Wheat Straw mulch; T_4= Poultry Manure; T_5= Vermicompost

Figure 4.12: Spike length in response to different mulch treatments

4.3 Cost analysis

All of the mulches show good results but compost mulch was highly efficient in all aspects. Cost of mulch materials is shown in table 4.2. Vermicompost mulch will increase percentage of organic matter, as well as good in terms of soil moisture conservation. The higher percentage of organic matter will also lead to better structure, reducing aggregation especially in clay soils. Further, moisture conservation through straw mulch can also be achieved for low cost treatment.

Table 4.2: Mulch materials rate comparison

Sr. No.	Mulching Material	Cost (Rs/Kg)	Cost / Hectare (Rs)
1	Vermicompost	75	4576
2	Farmyard manure	5	1200
3	Wheat straw	4	1105
4	Poultry litter mulch	10	2762

CHAPTER **5**

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Although present study is limited to short duration i.e. one crop for one season at a single site only. However, based on data gathered suggest that different mulches have variable impact on each attribute of the crop.

1. In general conservation of moisture, due the presence of mulch materials, enhanced germination and growth of crop plants. Presence of adequate moisture is the key to survival and production of plants in the arid areas.
2. Results of this study revealed that pots, where compost mulch was applied as treatment had relatively more moisture content compared with other three treatments as well as control (normal condition). Other than compost, farmyard manure mulch showed good results.
3. It was observed that more weight per plant was obtained from the pots with compost treatment followed by farmyard manure. This can be attributed to decomposed organic matter containing more available nutrients and readily available source of energy thereby utilizing less effort of microbes for decomposing wheat straw and poultry litter etc. Moreover, higher temperature is expected in case of raw material than already decomposed organic matter i.e. compost and farmyard manure. This also enriches the soil, improves its structure and drainage and provides plants with nutrients that promote strong, healthy growth which is finally expected to boost plant yield.

4. It was also observed that amount of macronutrient and total soil organic matter contents were higher in case of compost mulch, as it further enhances nutrient level of soil by biodegradation/mineralization phenomenon. Analysis of results also reveal that straw Mulch can be considered potential candidate for soil moisture retention but it does not release soil nutrients when compared with other tested mulch materials. Literature also suggest that wheat straw further limits soil erosion and improves soil structure when applied as mulch or covering on soil. This concept is further supported by looking into the application of straw as mud plaster since centuries in our villages/farm houses in order to protect them from the direct effect of rains.
5. In general, the mulches maintained the humidity right at the soil surface, and prevented airflow which retards evaporation process thus keeps the moisture in the soil available for plant uptake. After harvesting crops, these mulches can be incorporated into the soil that will further increase soil organic matter and in return may improve soil water holding capacity. The higher percentage of organic matter will also lead to improved soil structure. Even in situations where a manager has to purchase the mulching material such as straw, the savings in water and improvement in crop performance coupled with the soil building properties would likely justify the cost.

5.2 Recommendations

1. Achieving food security and sustainable development of agriculture in rainfed areas is of prime importance in the developing and less privileged communities. As a result of limited study and previous research results in the country, it can be highlighted that effective water management practices are critical for increasing wheat production and mulching can help achieving this objective. The results have proven this concept of better growth.

2. It is suggested that a combination of wheat straw (by product of wheat crop and readily available) with compost/farmyard manure, if applied as mulch, could serve as a moisture conservation practice in the periods of droughts. Mulch materials also get decomposed after harvesting which further enhances the availability of nutrients.
3. Based on findings of this study it is strongly suggested to spread the word of mulches among poor farming community of arid /water deficient areas to popularize this idea. These mulch materials are:
    - Abundantly available at affordable price
    - Easy to apply
    - Material stays in place
    - Decomposes to release organic matter in the soil
    - Provides resistance against weeds, insects and diseases (can be studied through research)

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