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Growth and Yield of Wheat (Triticum aestivum L.) as Affected by Mulching and Irrigation

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University of Rajshahi

Ph. D.
Thesis

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Ph. D. THESIS

Submitted by

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Session: 2008-2009

June, 2016

Agronomy Field Laboratory
Department of Agronomy and Agricultural Extension
Faculty of Agriculture
University of Rajshahi
Rajshahi-6205, Bangladesh

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To my beloved parents

DECLARATION

I hereby declare that the whole work reported in this thesis entitled **"Growth and Yield of Wheat (*Triticum aestivum* L.) as Affected by Mulching and Irrigation"** for the degree of Doctor of Philosophy of the University of Rajshahi, Bangladesh, is based on my original investigation. This work has not been submitted before of this University or any other institution to obtain a degree or any other academic certificate, honour or title.

…………………………
(Shaela Kabir Khan)
Candidate

CERTIFICATE

We hereby certify that the research work entitled **"Growth and Yield of Wheat (*Triticum aestivum* L.) as Affected by Mulching and Irrigation"** now submitted for the degree of Doctor of Philosophy in the subject of Agronomy is a bonafide research work carried out by **Shaela Kabir Khan** under our supervision in the University of Rajshahi, Rajshahi-6205, Bangladesh. The results of the investigation, which embodied here are original and have not been submitted before in substance for any other degree of this or any other university.

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The author

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Abbreviations and acronyms

AEZ	Agro-ecological zone
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
CGR	Crop growth rate
CPE	Cumulative pan evaporation
CRI	Crown root initiation
CT	Conventional tillage
CV	Coefficient of Variation
cv.	Cultivar
CWR	Crop water requirement
DAA	Days after anthesis
DAS	Days after sowing
DI	Deficit irrigation
DMA	Dry matter accumulation
DT	Deep tillage
ET	Evapotranspirations
et al.	*et alia* (and others)
FAO	Food and Agriculture Organization of the United Nations
FW	Fresh weight
FYM	Farmyard manure
HI	Harvest index
HYVs	High yielding varieties
I_0	No irrigation

I_1	2 cm of irrigation (an irrigation level used in this study)
I_2	4 cm of irrigation (an irrigation level used in this study)
I_3	6 cm of irrigation (an irrigation level used in this study)
i.e.	*id est* (it is)
IW	Irrigation water
IWUE	Irrigation water use efficiency
kg ha^{-1}	Kilometres per hectare
LAI	Leaf area index
LAR	Leaf area ratio
LS	Level of Significance
LWR	Leaf weight ratio
M_0	No mulch
M_P	Black polythene (used as a mulching treatment in this study)
MRC	Moisture retention capacity
M_S	Rice straw (used as a mulching treatment in this study)
MSWC	Minimum soil water content
M_W	Water hyacinth (used as a mulching treatment in this study)
NAR	Net assimilation rate
NCP	North China Plain
NPK	Nitrogen, phosphorus and potassium
NS	Non-significant
OD	Optical density
q ha^{-1}	Quintals per hectare
RA	Reproductive allocation

RCBD	Randomised Complete Block Design
RGR	Relative growth rate
RLGR	Relative leaf growth rate
RLWC	Relative leaf water content
RWC	Relative water content
SDM	Minimum soil water content
SLA	Specific leaf area
SWC	Soil water content
TDM	Total dry matter
$t\ ha^{-1}$	tonne(s) per hectare
UK	The United Kingdom of Great Britain and Northern Ireland
USA	The United States of America
V_1	Prodip (a variety of wheat)
V_2	Sufi (a variety of wheat)
var.	Variety
WSITs	Water-saving irrigation technologies
WUE	Water use efficiency
ZDT	Zero tillage with zone disc tiller

ABSTRACT

The experiment was conducted at the Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi Campus, Bangladesh during the winter seasons (November to March) of 2008-2009 to 2009-2010 to study the growth and yield of wheat (*Triticum aestivum* L.) as affected by mulching and irrigation. The study considered three factors viz. four levels of irrigation (0 cm=I_0; 2 cm=I_1; 4 cm=I_2 and 6 cm=I_3), four types of mulching (no mulching=M_0; water hyacinth=M_w; rice straw=M_S and black polythene=M_P) and two BARI released wheat varieties (Prodip=V_1 and Sufi=V_2). The experiment was laid out in split-split plot design assigning irrigation to the main plot, varieties to the sub-plot and mulching to the sub-sub-plot. There were three replications for each treatment.

The highest TDM, LAI and CGR were obtained from the highest level of irrigation (I_3) and the lowest values were obtained from control in both the years. With few exceptions LAR and SLA showed the highest values at I_3 treatment every year. At the initial stage of growth, LWR showed the highest value in I_0 but from 50 DAS it was reversed and I_3 treatment showed the highest values in both the experimental years with a few exceptions. RGR, RLGR and NAR did not show any clear pattern in both the growing seasons.

Between the two varieties, Prodip showed higher values in TDM, CGR and NAR and Sufi was superior over Prodip in producing higher values of LAR and LWR in both the years. RGR, RLGR and SLA did not follow any clear trend of superiority between the two varieties.

Results also revealed that, the highest values of TDM, LAI and CGR were obtained from M_P followed by M_S, M_W over no mulch treatment in both the years. With some exceptions the highest RGR values were found in MP but the difference between M_P and M_S were too narrow. NAR, RLGR and SLA did not show any fixed trend in the highest and the lowest values. M_P showed the

highest values in LAR with some exceptions in both the years. LWR almost showed the same values as influenced by M_P and M_S treatments.

Moisture retention capacity (MRC) of the flag leaf was increased with increased irrigation levels. The highest MRC was found in I_3 treatment over the control treatment. Prodip showed higher MRC than Sufi at each time of the experimental day. In case of mulching treatments, M_P showed the highest MRC followed by M_S and M_W. The highest value of MRC was always shown by $I_3 \times M_P$ treatment combination.

Non-irrigated plants showed lower relative leaf water content (RLWC) at each time of the experimental day. The highest RLWC was observed in I_3 followed by I_2, I_1 and I_0. $I_3 \times M_P$ treatment combination always had the highest value of RLWC.

Chlorophyll content of the flag leaf was increased with increasing levels of irrigation. I_3 treatment produced plants containing the highest amount of chlorophyll a, chlorophyll b and total chlorophyll followed by I_2, I_1 and I_0. The highest amount of chlorophyll a: b ratio was produced by I_0 treatment in both the years.

All the yield components such as plant height, total tillers plant^{-1}, effective tillers plant^{-1}, non-effective tillers plant^{-1}, spike length, extrusion length, number of spikelets spike^{-1}, number of fertile spikelets spike^{-1}, number of sterile spikelets spike^{-1}, 1000-grain weight, grain yield, sraw yield, biological yield and harvest index were observed with their highest values in I_3 (irrigation level) and M_P (mulching treatment).

Thus, it is concluded that growth, development and yield of wheat can be increased by using the combined treatment of 6 cm of irrigation and black polythene.

CHAPTER ONE

Introduction

Wheat (*Triticum aestivum* L.) has been established as one of the major cereal crops of the world both in area and production. It ranks first in acreage as well as production among the crops of the world (FAO, 2010). It has been used as food by human being since prehistoric days and considered as the 'King of Cereal Crops' because its cultivation is easier, nutrient content is high and ecologically suitable. Wheat is the second crucial staple food crop next to rice in Bangladesh (Razzaque and Hossain, 1991). It is preferable for its higher grain protein content (about 12%). At present about 8.44 lac tonnes of wheat is produced from an area of about 3.88 lac hectares of land having an average yield of 2.18 t ha^{-1} (FAO, 2010).

Wheat is the most important crop, contributing 45 percent of digestible energy and provides 30 percent of total carbohydrates in the human diet. It has not only a great contribution in human diet but also baby food, bakery industry and feeding of poultry and livestock (Evans, 1993). It is a great source of nutritious food having 12 percent protein, 1.72 percent fat, 69.60 percent carbohydrate and 27.2 percent minerals (BARI, 1997).

Bangladesh being an overpopulated country is running in shortage of food and becoming chronic problem for the country. As a result, Bangladesh has to import a large quantity of cereals. Wheat can play a vital role in the national economy of Bangladesh to close the gap between food production and import, because the water requirement of wheat is low compared to that of Boro rice in Rabi season. It is not affected by floods or hailstorms and less affected by pathogens. As it requires less water, almost one-third or one-fourth of Boro rice (BARI, 1982), the farmers of Bangladesh can get an opportunity to grow wheat with lower production cost and without keeping the land in fallow and can increase the agricultural production. In spite of all these advantages, the average yield of wheat is much lower in Bangladesh compared to other wheat producing countries. In Holland, UK, France and Norway, the average yield of wheat is 8.73, 8.28, 7.10 and 4.94 t ha^{-1}, respectively. Whereas it is only 2.18 t ha^{-1} in year 2008 in Bangladesh (FAO, 2010).

In Bangladesh, wheat is grown during the dry winter months from November to March. During this period rainfall is scanty and often uncertain and evapotranspiration is high. As a result, most of the time the crop suffers from water stress and this stress limits root growth and development. Since the stored moisture in most of the soil is inadequate to meet the evapotranspirational demand, wheat undergoes moisture stress of different intensities. As a result, production of wheat decreases. Slight water deficits in the vegetative period may have a little effect on crop development or may even somewhat hasten maturation (FAO, 2008). The flowering period is the most sensitive to water deficit. Pollen formation and fertilization can be seriously affected under heavy water stress and during the time of head development and flowering water shortage reduces the number of spikes $plant^{-1}$, spike length and the number of grains $spike^{-1}$. At the flowering stage, root growth is very much reduced and may even cease and considerable damage can be caused in this period. The loss of production due to water deficits during flowering period cannot be recovered by providing adequate water supply during the later growth periods.

Water stress at yield formation period results in reduced grain weight. Singh *et al.* (1979) found from their experiment for few years with tall wheat varieties that wheat is sensitive to water stress at the early growth stages. The yields of plant receiving stress at tillering were generally higher than yields of plant having stress at booting stage (Campbell, Davidson and Winkleman, 1981). This indicates that the plant has the ability to adapt to early stress and the period of gametogenesis, pollination, fertilization and seed development is critical to moisture stress for grain yield.

The moisture content in the soil gradually decreases with passing time in dry season and simultaneously soil moisture tension increases. At a very high tension, plants cannot absorb water from the soil through root zone and as a result it has an ultimate impact on crop yield. Physiological processes associated with anthesis and early grain developments are generally vulnerable to water deficit. Irrigation is an important factor which influences grain yield and quality of wheat. With proper irrigation facilities, much of the areas which remain fallow can be cultivated for growing wheat. Lack of irrigation facilities was found to be major constraint for 38 percent wheat growers and 25 percent of the farmers of Bangladesh could not grow wheat due to this problem (Ahmed and Elias, 1986). So, supplemental irrigation is necessary to ensure proper growth and yield of wheat. But irrigation increases the cost of production.

Thus, mulching could be an effective cultural practice alternative to irrigation to maintain the soil moisture status leading to an increase of wheat yield in Bangladesh. Mulching materials are often cheap and often readily available as crop residues, crop by products (i.e. rice straw); different types of unwanted vegetation, for example, water hyacinth. They protect the soil from erosion, conserves moisture which reduces the need for frequent irrigation, maintains more even soil temperature and prevent weed growth. Organic mulches also improve the condition of soil. As these mulches slowly decompose, they provide organic matter which helps to keep the soil loose. This improves root growth, increases the infiltration of water, and also improves the water holding capacity of the soil. Organic matter is a source of plant nutrient and provides an ideal environment for earthworms and other beneficial soil organisms which ultimately increase the yield of crop. Higher soil water contents and reduced evaporation are major reasons for improved germination, emergence and seedling growth due to mulching. So it can be said that mulching is not only economic but also environment-friendly agronomic practice and if it is used to produce wheat accompanied with proper irrigation scheduling, the farmers will be benefited socio-economically by obtaining higher yield of wheat.

OBJECTIVES OF THE STUDY

1. To determine optimum amount of irrigation water and mulching for getting the maximum growth and yield of wheat;

2. To find out the effect of different sources of mulching materials;

3. To determine the effect of mulches on soil moisture conservation; and

4. To investigate the combined effect of irrigation and mulching on the growth and yield of wheat.

CHAPTER TWO

Review of literature

Wheat (*Triticum aestivum* L.) has been established as the second most economic food grain crop to minimise the gap between food production and international food trade in Bangladesh. BARI developed and released a number of HYVs of wheat that need extensive studies with different inputs. Researches on different aspects of wheat have been carried out in universities and research institutes across the world including Bangladesh. In this chapter, an attempt has been made to review some of the available information related to growth and yield of wheat varieties and presented below.

2.1 EFFECTS OF IRRIGATION

2.1.1 Effects of irrigation on the growth and physiological attributes

Pal *et al.* (1979) conducted a field experiment during winter season of 1992-93 and 1993-94 on sandy loam of Ranchi, India. The treatment consisted of three irrigation schedules (two irrigations at CRI and booting stages; three irrigations at CRI, booting and milk stages; and four irrigations at CRI, maximum tillering, booting and milk stages) and observed that application of four irrigations gave higher crop growth rate (CGR) than two or three levels of irrigation.

Rahman *et al.* (1984) conducted an experiment in especially designed earthen pots in a completely randomised design in the premises of Soil Science Department, University of Dhaka during the months of November 1980 to April 1981 using four irrigation treatments (A_1, A_2, B_1 and B_2) having no drainage and evaporation losses mechanism (‘A’ type boxes with irrigation channel) and also allowing drainage and evaporation losses (‘B’ type boxes, gravity irrigation) to evaluate the growth, yield and quality of wheat plant (cv. Sonalika) grown in sand and sandy soil. Maximum growth and yield were obtained in A_2 treatment and minimum in B_2 treatment. They also reported that the supply of water and nutrients to the channel irrigation system (‘A’ type box) for sand and sandy soil may be useful with respect to the growth, yield and quality of wheat.

Talukdar (1987) worked on the growth and development of wheat as affected by soil moisture stress. When Lysimeters were placed in the field and moisture stress was applied at various stages of growth, the early drought decreased the total dry matter, green leaf dry matter and green leaf area index during the early stages of ‘Sappo’ spring wheat. Re-watering resulted in an increase in these characters during the grain formation stage due to the development of a considerable number of late tillers.

Guiducci (1988) observed that irrigation during grain filling caused a lengthening of the dry matter accumulation period and a decrease in the accumulation rate.

Leverton (1990) worked on the effect of competition and water availability on tillering and growth of wheat. According to him, both spring and winter wheat cultivars were affected and resulted in reduced leaf growth rates, particularly in tillers and reduced leaf area index when experienced water stress.

Simane *et al.* (1993) noticed that the pre-anthesis moisture stress delayed phenological development whereas post-anthesis moisture stress accelerated it. They conducted a greenhouse experiment to study the response of five durum wheat cultivars to moisture stress at different development phases. Phenology, TDM, RGR, LAR, NAR, LWR, and SLA were compared. TDM accumulation rate differed between the drought resistant and susceptible cultivars. RGR and its components changed with age and moisture availability. Drought resistant cultivars had a higher RGR in favourable periods of the growing season and a low RGR during moisture stress. In contrast, the drought susceptible cultivars showed an opposite trend. LAR explained the differences in RGR best, whereas the relationship between NAR and RGR was not significant. Even though both LWR and SLA were important factors determining the potential growth rate, LWR was of major important to describe cultivars differences in LAR and consequently in RGR. They concluded that biomass allocation was the major factor explaining variation in RGR.

Sairam (1993) reported that water stress decreased relative water content (RWC) and other metabolic activities of wheat cultivars C 306 and HD 2329.

Saha and Paul (1995) studied the effect of soil moisture on the growth parameters such as RGR, NAR, LAR, RLGR and LWR of five wheat cultivars. LAR, RLGR and LWR were increased but NAR was decreased and RGR was unaffected by soil moisture. All the growth parameters decreased with plant age except NAR and RLGR which increased at the later stage of growth. They further reported the increase of grain yield due to soil moisture was not related to growth parameters.

Sarker *et al.* (1996) studied the effect of soil moisture on shoot and root growth of four wheat varieties (Opata, BL 1183, C 306 and Kanchon) in two seasons. There were two soil moisture treatments: plants were watered daily and at five to six-day intervals. Dry weight of leaf, stem, panicle length and total dry weight, total leaf area and all the growth attributes except RGR and RLGR were higher in the well-watered plants than the water stressed plants. RGR and RLGR were slightly higher in the water stressed plants.

Ashok and Sharma (1997) conducted field trial in winter seasons of 1990-91 and 1991-92 in Karnel, Haryana, India, where wheat cv. HD-2285 was irrigated at IW: CPE ratios of 0.6, 0.9 or 1.2. it was observed that all the irrigation treatments increased dry matter accumulation.

Nahar and Paul (1998) conducted an experiment to study the effect of two soil moisture regimes on dry matter production, leaf area and some growth attributes of two wheat cultivars such as Sonalika and Kanchon. The two soil moisture regimes were irrigated and rain-fed control. Significant effect of irrigation was observed for TDM and LAI at some of the growth stages studied. TDM was greater in the irrigated than in the rain-fed plants. LAI was also greater in irrigated plants except in a few cases of Kanchon. Among the growth attributes, CGR and SLA were significantly increased and NAR and LAR were decreased by irrigation. CGR at post-flowering stage was significantly associated with grain yield.

Sarker and Paul (1998) studied the different growth attributes of four wheat varieties such as Opata, BL 1183, C 306 and Kanchon under irrigated and rain-fed conditions. Results obtained revealed that the CGR, LAR and LWR were higher in the irrigated plants compared to rain-fed plants. No definite pattern was found for RGR, NAR, RLGR and SLA in the irrigated and rain-fed plants, but all of them except SLA declined with increasing age and plant dry weight. The decreasing tendency was found in SLA and the middle stages of growth. Higher values of CGR were found in irrigated C 306; RGR, LAR and LWR in the irrigated Kanchon;

RLGR and SLA in the rain-fed Kanchon and NAR in the rain-fed BL 1183.

Dotlacil and Toman (1999) found that the highest LAI gave the highest seed yield (6.98 t ha^{-1}). They also observed that seed yield was positively correlated with LAI.

Mugabe and Nyakatawa (2000) observed that the growth of wheat decreased when 50%-75% of required water were supplied.

Wang and Li (2002) conducted a plot experiment in a greenhouse to study the effects of water deficit and irrigation at different growing stages of winter wheat and observed that water deficiency retarded plant growth.

Tomar *et al.* (2003) conducted a series of field experiments in Pantnagar on a silty clay loam (Typic Hapludoll) to determine the suitability of wheat cultivars by characterizing their plant water relationships, growth and productivity under shallow water table conditions in the Tarai region of Uttarkhand, India. The treatments consisted of five soil moisture regimes: rain-fed (control), irrigation at crown root initiation (CRI), irrigations at CRI and flowering stages (well-watered), irrigations when canopy temperature variability was >=0.70 and irrigations at pre-dawn xylem water potential (XWP) of -0.35, -0.65, -0.65, -0.65 and -1.45 MPa at CRI, late tillering, late jointing, flowering and milk stages, respectively, based on the stress day index concept) in the main plot and 8 wheat cultivars (UP 115, UP 368, UP 2113, HD 2281, HD 2285, C 306, WL 410 and RR 21) in the subplot. Under rain-fed condition, the highest leaf area index (LAI) was found in C 306 and the lowest in UP 368, while under well-watered condition, the trend was reversed. The maximum percentage reduction in LAI was observed in UP 368 and the minimum in C 306.

Rahman *et al.* (2005) conducted an experiment to evaluate the effect of irrigation and split application of nitrogen on plant growth and yield of wheat. TDM, LAI and CGR increased with the increased number of irrigations. Three irrigations at CRI, tillering and heading stages produced the highest TDM, LAI and CGR and the lowest values were found in control. NAR fluctuated due to irrigation. The rain-fed plants had higher LAR and SLA. At early stage, variety Gourab produced higher TDM, LAI, CGR, NAR and at the later stage, while variety Saurav produced higher TDM, LAI, CGR, NAR and LAR.

2.1.2 Effects of irrigation on the yield and yield components

Misra *et al.* (1969) reported that applying no irrigation at the crown root initiation stage and flowering stage adversely affected tillering, grain yield and 100-grain weight of wheat. They also observed that the grain yield increased with four irrigations applied at the crown root initiation, late tillering, flowering and dough stages.

Verma *et al.* (1970) conducted an experiment with wheat in irrigated condition and found that three irrigations gave significantly higher yield over two irrigations and the differences between three and four irrigations were not significant. It appeared that irrigation at tillering stage initiated more numbers of healthy tillers which was directly reflected upon the yield.

Patel *et al.* (1971) reported that omitting irrigation at crown root initiation and at late tillering stages significantly reduced the plant height, number of tillers per plant, length of ear head and thereby the number of grains per panicle.

Srivastava (1972) conducted an experiment on wheat irrigated at 30-60 percent available soil moisture and nitrogen was applied at the rate of 100 kg Nha^{-1} in equal two split halves at sowing and rest half at crown root initiation stage (CRI) and jointing stage. He found that when the crop was irrigated at 60 percent available moisture with splitting of nitrogen at sowing and CRI stage gave the highest yield of grain.

Anonymous (1975) reported that the irrigation had a significant effect of plant height, total and effective number of tillers per plant, panicle length, total and fertile grains per panicle, straw and grain yields, except 1000-grain weight. Four levels of irrigations, such as no irrigation, one irrigation (only at 22 days after sowing) and three irrigations (at 22, 45 and 65 days after sowing) were used. The highest yield of grain and straw were obtained with three irrigations. The height of the plants, total and effective tillers per plant, panicle length, total and fertile grains per panicle, straw and grain yields were gradually increased with the increased number of irrigation.

Pal *et al.* (1979) found at the Bundelkhand region of India that three irrigations given at CRI, tillering and milk stages produced higher grain yield than two irrigations at CRI and milk stages for durum wheat. They also added that one irrigation at CRI stage significantly increased yield over control.

Saxena and Singh (1979) mentioned that grain yield of wheat increased by three irrigations over two irrigations. Maximum grain yield (2.7 t ha^{-1}) was observed by three irrigations which was statistically superior irrigation at CRI stage significantly increased yield over control.

Malik (1980) in India observed over three years of trials that the average grain yield of wheat increased from 2.68 to 4.42 t ha^{-1}, in Kalyansona with the increasing number of irrigations from 1 to 4 applied at CRI, tillering, flowering and dough ripeness stages.

Singh *et al.* (1980) stated that wheat yield increased due to application of two irrigations given at CRI and heading stages over single irrigation at CRI stage. Beneficial effect of supplemental irrigations applied to wheat was because of significant improvement in all the three important yield contributing characters such as number of years per metre row length, number of grains per year and 1000-grain weight.

Koshta and Raghu (1981) carried out an experiment with three irrigation treatments (two splits: two-third nitrogen as basal + one-third nitrogen at CRI, and one-third nitrogen as basal + two-third nitrogen equally spread over irrigations). Six irrigations with 21 kg N ha^{-1} in two splits: two-third as basal and one-third at CRI gave significantly higher yield than any of other treatments.

Malik (1981) conducted an experiment where five doses of nitrogen (0, 40, 80, 120, 160 kg ha^{-1}) with three splits: a half at sowing, a quarter at first and fourth quarter at second irrigation and six levels of irrigations were applied from 20 days after sowing with an interval of 15-20 days until the maturity, covering all critical stages of crop. He found the increased grain yield with increasing nitrogen levels up to 120 kg ha^{-1} in three splits under irrigated condition. He also observed that increasing N rates applied to two irrigated wheat cultivars increased effective tillers per plant and seeds per spike.

Rahman *et al.* (1981) reported that the yield of wheat was highest and irrigation efficiency was maximum when two irrigations, totalling 9.5 cm, given at tillering and booting stages. The lowest grain yield was obtained in the treatments where irrigation was given at the grain filling stage.

They also argued that a significant yield increase of wheat might be possible from supplemental irrigation; the magnitude of response would, however, vary with the rainfall distribution during the cropping season as regards yield components, they observed that 1000-grain weight and harvest index were not significantly affected by irrigation.

Rao and Bhardwaj (1981) indicated that grain yield of wheat increased with increasing number of irrigation.

Idris and Karim (1982) reported that when three irrigations given at CRI, tillering and booting stages produced the highest grain yield of wheat. They also found that irrigation applied at CRI, tillering, booting and grain filling stages decreased yield slightly. They further stated that grain yield increased over control by 86 percent just by applying water only one at the tillering stage.

Hefni *et al.* (1983) reported that irrigation played a positive role in increasing the number of tillers, ear per plant and grain of wheat. Ear length and number of grains reduced significantly if irrigation was stopped at tillering and booting stages of wheat.

Quayyum and Kamal (1986) observed that application of irrigation at all the critical growth stages significantly increased yield of wheat over control. They also found that CRI stage showed the highest response irrigation in increasing grain yield when only one irrigation was given. They added that for two irrigations, CRI and maximum tillering stages and for three irrigations, CRI, maximum tillering and grain filling stages were effective for increasing grain yield. Yield ranged from 2.07 t ha^{-1} without irrigation to 4.09 t ha^{-1} with four irrigations.

Jana and Mitra (1989) observed that two irrigations at the tillering and flowering stages produced the highest grain yield.

Upadhyaya and Dubey (1991) conducted an experiment where the treatments consisted of three irrigation frequencies, one irrigation (at CRI stage), two irrigations (one each at CRI and booting stages) and four irrigations (one each at CRI, booting, flowering and milking stages). Four irrigations produced the maximum grain yield which was significantly higher than two or one irrigation. The increased yield was due to the favourable effect of treatments on yield attributing characters.

Labuschange and Van-Deventer (1992) investigated five winter wheat and their F_1 hybrids by maintaining the material at 80 percent and 50 percent field capacity. Yield, grain number and grain weight on the secondary tillers were affected severely by moisture stress. Grain number and grain weight on both primary and secondary tillers were significantly correlated with yield at both moisture levels.

Bajwa *et al.* (1993) found that the maximum grain yield of wheat was with three irrigations than with no irrigation.

BARI (1993) reported that maximum grain and straw yields were recorded with three irrigations applied at CRI, maximum tillering and grain filling stages of crops. Irrigation given at CRI + maximum tillering, CRI + booting and CRI + grain filling was at par in respect of number of spikes per square metre and grains per spike, but had highest spikes and grains over CRI + maximum tillering stages.

Saha and Khan (1993) reported that plant height and 1000-grain weight were not significantly increased by irrigation. Increase in number of irrigation may increase spikelets fertility and decrease sterility.

Singh and Uttam (1993) conducted a field trial on wheat under irrigated condition and observed that three irrigations at CRI, late tillering and flowering stages produced higher yield than one irrigation applied at booting stage.

BARI (1994) reported that maximum grain and straw yields were recorded with three irrigations applied at CRI, maximum tillering and grain filling stages of the crop.

Jana and Misra (1995) carried out an experiment on wheat cultivar Sonalika giving irrigation at CRI, tillering, flowering and dough stages. They also found that irrigation increased plant height, number of effective tillers ear^{-1}, grain and straw yields.

Pratibha and Ramaiah (1995) found that irrigation increased grain yield. They also observed that eight irrigations get the highest grain yield.

Yadav *et al.* (1995) reported that two irrigations scheduled at CRI and milk stage gave the maximum plant height (1.026 m), number of grains ear^{-1} (65), straw (4,500 kg ha^{-1}) and grain (3,168 kg ha^{-1}) yields of wheat which were found at par with those at one irrigation.

Muhammad-Jamal *et al.* (1996) reported that low water stress affected wheat yield components. They grew three cultivars of wheat and subjected them to water stress (-10 bars leaf water potential) at the tillering, jointing, booting and anthesis stages. Water stress significantly decreased panicle length and grain weight per panicle compared with the unstressed controls. Water stress at anthesis was most critical for grain formation. They also reported that water stress applied at tillering did not significantly affect grain number spike^{-1}. Mean grain yields were also decreased due to the application of water stress at any growth stage.

Rahman and Paul (1996) stated that the irrigated wheat plants had higher panicle weight than the rain-fed plants at all the stages of growth but significant effect was observed at 14 days after anthesis (DAA) in Akbar, 7 and 28 DDA in Barkat. Akbar had significantly higher panicle growth rate than the Barkat in both the irrigated and rain-fed conditions. Grain weight increased very sharply with increasing time in both the cultivars. The irrigated wheat plants had higher grain weight than the rain-fed plants.

Razi-us-shams (1996) observed that the effect of irrigation treatments in yields and yield contributing characters were significantly significant. When irrigation frequency was increased grain and straw yields, number of tillers, panicle length and number of grains per panicle were gradually increased over control.

Islam (1997) reported that the effect of different irrigation treatments on the grain and straw yields and yield contributing characters gradually increased with increasing number of irrigations. The highest grain and straw yields, the maximum plant height, the highest number of effective tillers and the maximum number of grains per spike were obtained by three irrigations (I_4) applied at 25, 50 and 70 days after sowing. The increase in the grain and straw yields in I_4 treatment over control was 60.7 percent and 59.4 percent respectively.

Naser (1997) reported that the effects of different irrigations on yield and yield attributing characters were statistically significant. Two irrigations at 30 and 50 DAS significantly increased grain and straw yields over control. The highest grain and straw yield, the maximum number of tillers plant^{-1}, the highest spike length, the maximum number of grains spike^{-1} were recorded in I_4 treatment where two irrigations were applied. The I_4

treatment increased grain and straw yields by 58.1 percent and 54.5 percent, respectively over control treatment which showed the lowest result in all parametres.

Sarker and Paul (1997) studied the effect of soil moisture on growth, yield and quality of four varieties of wheat such as Opata, BL 1183, C 306 and Kanchon in field experiment. There were two treatments: plants were irrigated five times throughout the whole growing period and no irrigation (rain-fed) was applied. Total dry matter production, plant height, tiller number and leaf number were higher in the irrigated plants than the rain-fed plants. Phenological characters also showed their higher values in the irrigated plants except duration of anthesis, where slightly higher value was observed in the rain-fed plants. However, protein content was greater in the rain-fed plants. Again, all the characters related to yield except number of spikelets per spike and numbers of florets per spikelet were significantly increased by soil moisture.

Wada *et al.* (1997) conducted an experiment with 20 cultivars of wheat (12 Brazilian, five Mexican and three Japanese) with four levels of irrigation. They also reported that 1000-karnel and grain weight showed a sequence in dry plots but little difference in irrigated plots. Irrigation has a significant effect on increasing 1000-grain weight of wheat.

Meena *et al.* (1998) conducted a field experiment in 1993-95 at New Delhi on bread wheat (cv. HD 2265) with no irrigation or irrigation at flowering and crown root initiation stages. The study also reported that wheat grain yield was the highest with two irrigations (2.57 t ha^{-1} in 1993 and 2.64 t ha^{-1} in 1995).

Rahman and Paul (1998) studied the effect of soil moisture regimes and observed that the irrigated plants had significantly higher extrusion length, panicle length, 1000-grain weight, harvest index and grain yield than the rain-fed plants.

Biswas *et al.* (1999) conducted a field experiment in Mymensingh, Bangladesh, during the rabi season of 1990-91 to study the effect of sowing rate (80, 120, 160, or 200 kg seeds ha^{-1}), N split application (at early tillering and ear emergence stages, or at early tillering, late tillering, and at one week after anthesis), and irrigation schedule (before or after N application) on wheat cv. Kanchan. Sowing and harvesting were conducted on 15 November 1990 and 20 March 1991, respectively. The sowing of 80 kg seeds ha^{-1} gave the tallest plants (82.2 cm) and the highest number of total (2.5) and effective (2.2) tillers per plant, ear length (8.5 cm), the number of spikelets ear^{-1} (14.6), the number of grains ear^{-1} (26.8), and 1000-grain weight. On the other hand, the number of ears increased with increasing sowing rate due to higher plant population per unit area. The highest grain yield was obtained with 80 and 120 kg seeds ha^{-1}. Grain protein content was highest with 120 kg seeds ha^{-1}. N split application significantly affected the number of ears and grains. Ear number was higher with N application at early tillering and ear emergence stages, whereas grain number was higher with N application at early tillering, late tillering, and at one week after anthesis. The schedule of irrigation did not significantly affect any of the parameters studied.

Siddique *et al.* (1999) conducted an experiment under semi-controlled condition at the Institute of Postgraduate Studies in Agriculture (IPSA), Bangladesh during November 1994 through March 1995. They evaluated drought stress effect on phenological characters of four wheat cultivars, such as Kanchon, Sonalika, Kalyansona and C 306 grown in pots to four level of water stress. They found that the reduction of plant height was severe in those plants which were subjected to drought stress both at vegetative and reproductive stage. Drought stress, either at vegetative stage or at anthesis stage, significantly decreased tiller numbers. Drought stress significantly reduced leaf area at one or both stages. Sonalika was the earliest cultivar which took 108 days to mature. The latest maturing cultivar was C 306 which took 122 days. They also reported that drought stress treatment effect on days to maturity were insignificant.

Dhafer *et al.* (2000) observed that the impact of wastewater complementary irrigation by the infiltration/percolation method in comparison to well water with fertilizer added – on the growth, water consumption and yield of durum wheat. It determined the yield increase in a crop started in dry conditions and developed suitable wastewater irrigation techniques for maximum production.

Adjetey *et al.* (2001) observed that grain yield response was greatly dependent on soil moisture or rainfall. Water availability at this time determined karnel weight and hence grain yield, even sufficient grain number had been established.

Halepyati (2001) reported that the effect of irrigation (60, 80 and 100 mm can evaporation level) on the stages of wheat cv. DWR-162 was investigated in Karnataka, India during 1996-97. Irrigation at 60 mm evaporation level resulted in higher grain and straw yields.

Ihsanullah and Fida (2001) conducted an experiment in Pakistan during 1996-97 on 17 breeding lines and seven varieties of wheat to determine the correlation of yield and yield component. High yielding disease resistant breeding lines were also isolated. The genotypes had highly significant differences for stripe rust disease wherein the genotypic correlations of stripe rust with harvest index was negative indicating that grain formation was more affected than vegetative growth. Genotypes also showed highly significant differences for days to heading, plant height, main stems and tillers. Correlations of lodging with plant height was significant but was non-significant with 1000-grain weight, yield and harvest index. The correlation of 1000-grain weight and yield was significant with harvest index.

Liu *et al.* (2001) stated that, after the application of various levels and durations of water stress at different growth stages, rewatering greatly stimulated the leaf area of winter wheat. Results showed that this stimulation was affected by the stress level and duration, and the period at which it occurred. The stimulation of the earlier stress, followed by rewatering, was greater than that of the later stress. Severe water stress promoted the stimulation more than the moderate stress, while longer duration of stress decreased it. However, the final leaf area under severe stress or under longer duration recovered to a lesser degree than that under moderate stress or under shorter duration. No matter in which growth stage the stress occurred, the stimulating mechanism was the same: the increase of total leaf area resulted from the increase of the leaf area of the tillers. Once the leaf on the main stem emerged during stress period, rewatering had no effect on its size, and consequently, on its leaf area. The stimulation of rewatering on leaf area contributed 45 and 67 percent to the final grain yield under moderate and severe stress, respectively. Although the stimulation partly compensated for the loss during stress, the final leaf area attained and the corresponding grain yield could not recover to the control level.

Nourmand *et al.* (2001) conducted a field study in Iran to compare the morpho-physiological traits of 20 bread wheat lines under two different irrigation levels (presence and absence of moisture stress). Statistical analyses indicated that there were significant differences between the lines for the tested traits, and that all traits were negatively affected by drought stress. The grain yield was significantly reduced under drought stress due to the decrease in the grain weight of each spike during the grain filling period. The results indicated that spike number area^{-1} as well as seed number spike^{-1} should be increased to obtain high yield during drought. This would compensate for the yield reduction resulting from low mean grain weight. In addition, because of the effect of water stress on harvest index, straw and grain yields should also be increased. To obtain higher grain yield under normal conditions, the seed number spike^{-1}, number of spikes per unit area and 1000-grain weight should be increased. It is recommended to use late maturing cultivars to increase the vegetative period. Foliage growth should also be increased because of the negative effect of plant height on harvest index.

Pandit *et al.* (2001) stated that three times irrigation at CRI, booting and early grain filling stages resulted in higher grain and biological yield of wheat due to higher number of ears per metre, grains per ear and plant height as against no irrigation. But higher 1000-grain weight and harvest index were observed from no irrigation.

Rahman *et al.* (2001) conducted a field experiment to find out the effect of soil moisture on grain yield and yield components of eight cultivars (BAW 452, BAW 171, Paavon 76, Barkat, Opata, BL 1183, C 306 and Kanchon) of wheat. There were two treatments: five irrigations were given throughout the whole cropping period and no irrigation (rain-fed). Plant height, tiller number per plant, number of spikelets per main-spike, 100-grain weight, total dry matter per plant and grain yield were significantly increased in the irrigated plants than the rain-fed plants.

Rane *et al.* (2001) used six wheat genotypes differing in relative drought tolerance (HD 2329, Sonalika, Kundan, IWP 72, C306 and Narmada 112) to study the effects of pre-anthesis water deficits on photosynthesis, growth and yield. Plots subjected to water stress were not watered after the pre-sowing irrigation. After anthesis, irrigation was restored in the water-stressed plots. Kundan had the highest relative water content under stress at 53 days after sowing (DAS). Water stress moderately reduced photosynthesis rate (14-15%) in HD 2329, Sonalika and IWP 72 at 53 DAS. At anthesis, water stress greatly reduced photosynthesis rate in all cultivars except C306 and Kundan. Leaf area was affected adversely in both main shoot and tillers of all cultivars. Water-stressed HD 2329, Sonalika and Narmada 112 had more adversely affected leaf areas than other cultivars. The tillers showed a remarkable compensation in leaf area except in Sonalika when the water stress was relieved. The main shoot biomass was reduced in IWP 72, Kundan and Narmada 112, while the tiller biomass was reduced significantly in Sonalika and IWP 72. Results indicate that pre-anthesis water deficit adversely affected the main shoot grain yield of most of the cultivars. Stress-induced reduction in main shoot grain yield could not be explained by the effects on photosynthesis. Lower yields under pre-anthesis drought stress were due to reduction in both grain number and grain weight. C306, among the tall types, and Kundan, among the dwarf types, compensated better for the yield loss in main shoot by their tiller grain yield.

Yadav *et al.* (2001) conducted an investigation during the winter season of 1997-98 and 1998-99, at Morena, Madhya Pradesh, India to study the effect of irrigation schedule and application of pendimethalin on weed control, and plant growth and yield of wheat cv. IH 8381. The treatments consisted of three schedules of first irrigation (20, 25 and 30 days after sowing (DAS)) and weed control schedules (weedy control, and pre-emergence application of pendimethalin granules 10 percent at 1.0, 1.5 and 2.0 kg ha^{-1}). *Phalaris minor* and *Avena fatua* were the dominant grassy weeds, while *Chenopodium album*, *Anagallis arvensis*, *Convolvulus arvensis* and *Melilotus alba* were the major broad-leaved weeds. An adverse effect on the yield attributes and yields was observed on delaying or withholding first irrigation. Higher values of yield attributes and yield were observed when first irrigation was applied at 20 or 25 DAS compared with 30 DAS. All these parameters were higher under the application of pendimethalin at 2.0 kg ha^{-1}. Weed density was not affected by the irrigation schedules, but weed biomass reduced under delayed irrigation at 30 DAS during 1998-99 only.

Zhai and Li (2003) carried out a pot experiment with winter wheat and showed that water stress significantly inhibited the yield of wheat.

Moghadam and Ghahraman (2004) conducted an experiment in Mashhad region, Iran to investigate the effect of water stress on evapotranspirations (ET) and yield criteria of winter wheat. A complete randomized block design with 9 treatments and 3 replications were used. The first treatment (control treatment) was irrigated in all growth stages of the plant, six treatments were irrigated on the basis of no watering in a specific growth stage (germination, tillering, jointing, flowering, seeding and ripening) and the two remaining treatments were irrigated on the basis of 20 and 60 percentages of their potential water needs. The amounts of actual ET were determined in different experimental treatments by using the water balance equation. Plants subjected to water stress could not reach their potential ET after the end of stress period. In addition, water stress reduced the amount of plant coefficient and leaf area index. There was a significant difference in the amount of seed yield, harvest index, water use efficiency and yield components between control treatment and other treatments. Water stress also affected yield mainly via reduction in the weight of 1000 seeds and the number of seed in spike more than the number of spike per area unit.

Rahman (2004) conducted an experiment to evaluate the effect of irrigation and nitrogen application on the seed growth and yield of wheat with a few exceptions, the highest seed growth parameters like number of spikelets spike^{-1}, number of florets spike^{-1}, number of seeds spike^{-1} and seed growth rate were observed in two irrigations at CRI and tillering stages and three irrigations at CRI, tillering and heading stages at different days after anthesis (DAA). Only three irrigations produced the highest dry weight of spike and seed at different DAA. Saurav produced higher number of spikelets spike^{-1}, number of florets spike^{-1} and number of seeds spike^{-1} while Gourab produced higher dry weight of spike as well as seed and seed growth rate at different DAA.

Abdorrahmani *et al.* (2005) studied the growth rate, yield and yield components of four wheat cultivars (Sabalan/1-27-56-4, Anza/3/Pi/Nor//Hys/4/sefid, 4493-P.1533-Bez and Sabalan) under rain-fed conditions and two irrigation regimes (irrigation at planting time and ear emergence, and irrigation at planting time, ear emergence and grain filling) in Maragheh, Iran, during 1997-98. Crop growth rate, relative growth rate, dry matter accumulation per unit area, number of ears per unit area, number of grains ear^{-1}, 1000-grain weight, biological yield, grain yield, harvest index, plant height and productivity were evaluated. Drought stress reduced dry matter production, crop growth rate and relative growth rate. Green cover percentage, crop growth rate, and relative growth rate did not significantly vary among the cultivars. All traits except the number of grains per ear and harvest index were affected by water deficit. No significant variation was observed between irrigation regimes. The green cover percentage, plant height, crop growth rate, biological yield and productivity were significantly correlated with grain yield. The mean green cover had the greatest positive correlation with grain yield. This trait can be recommended as a suitable index for the evaluation of the field performance of various crops.

Ali *et al.* (2005) conducted a study on clay loam soil during 2000-02 at Adaptive Research Farm, Vehari to see the effect of different irrigation frequencies on the growth and yield of wheat (cv. Uqaab-2000). The results revealed that wheat crop receiving five irrigations at crown root + tiller + boot + milk + grain development stages produced significantly taller plants and maximum number of fertile tillers per unit area. It was, however, not significantly superior to four irrigations applied at crown root + boot + milk + grain development stages for the number of grains spike^{-1}, 1000-grain weight and grain yield. Plant height, 1000-grain weight and wheat grain yield were significantly higher under four irrigations applied at crown root + boot + grain development and crown root + boot stages of plant growth, respectively. A grain yield reduction of 6.63 and 12.20 percent and increase of only 1.45 percent was obtained by applying three, two and five irrigations, respectively as compared with four irrigations. It was concluded that four Irrigations proved to be sufficient obtaining reasonable wheat yield in cotton zone of southern Punjab in Pakistan.

Al-Rjoub (2006) conducted a pot experiment in a greenhouse as rainout shelter to investigate the response of diverse durum wheat (*Triticum turgidum var. durum* [T. durum]) cultivars (Om-quais, Hourani-27, Safra Ma'an and Al-Samra) to three levels of soil moisture: 50% (M_1), 65% (M_2) and 85% (M_3) of field capacity. The cultivars were good drought-tolerant because they were able to produce at M_1, which is 4.0 percent below the wilting point. The cultivars did not differ significantly for yield and yield components. The soil moisture very significantly affected all characters, except for harvest index. Increasing the soil moisture levels from M_1 to M_2 and from M_2 to M_3 caused a great increase of 136 and 77 percent for biological yield plant^{-1}, 143 and 63 percent for grain yield plant^{-1}, 93 and 77 percent for straw yield plant^{-1}, 93 and 43 percent for number of spikes plant^{-1}, 137 and 44 percent for number of kernels plant^{-1} and by 7 and 10 percent for thousand kernel weight, respectively. Under rain-fed conditions, supplementary irrigation can improve wheat yield and avoid crop failure by limited amount of water.

Zhang *et al.* (2006) reported that water supply at booting to heading stages promoted both spike and grain development.

Ali *et al.* (2007) conducted a field experiment for three consecutive years to study the effects of water deficit on yield, water productivity and net return of wheat. Yield attributes were affected by deficit irrigation treatments although they are not statistically different in all cases. The grain and straw yields were significantly affected by treatments. The highest grain yield was obtained with the no-deficit treatment. Differences in grain and straw yield among the partial- (single- or two-stage deficit) and no-deficit treatments are small and statistically insignificant in most cases. The results will be helpful in policy planning regarding irrigation management for maximizing net financial returns from limited land and water resources.

Khan *et al.* (2007) reported that, for the maximum yield of wheat, the crop may be irrigated after five-week interval. Excessive and earlier than five-week irrigation interval can be harmful for the optimum yield of wheat if the seasonal rainfall is ≥ 330 mm.

Rahman *et al.* (2007) conducted an experiment to evaluate the effect of irrigation and split application of nitrogen on plant characters at different phenological stages and yield of wheat. The result showed that with a few exceptions the highest plant height, leaf dry weight and leaf area were achieved in three irrigations and the lowest values for all these parameters were found in no irrigation at all the phenological stages. The variety Saurav had significantly higher plant characters.

Saleem *et al.* (2007) conducted a study at Agricultural Research Farm, NWFP Agricultural University, Peshawar, Pakistan during 1999-2000 to appraise the effect of water regimes at various growth stages on the performance of wheat. The irrigation treatments given to four wheat cultivars, Ghaznavi, Fakhre Sarhad, Tatara-96, and Bakhtawar-92 were: (I< sub>0</ sub>) no irrigation; (I< sub>1</ sub>) single irrigation at germination; (I< sub>2</ sub>) two irrigations up to tillering; (I< sub>3</ sub>) three irrigations up to anthesis; and (I< sub>4</ sub>) four irrigations up to the milk stage. Irrigations significantly affected spikes m^{-2}, spikes weight, 1000-grain weight, days to maturity and biological yield. Among cultivars, days to heading, spikes m^{-2}, plant height, spike weight, number of grains spike^{-1}, 1000-grain weight, days to maturity, biological yield and grain yield was significantly different. The interactive effect of irrigation and cultivars only affected biological and grain yield. Hence, all the irrigation levels produced significant differences in yield and components.

Waraich *et al.* (2007) stated that the reduction in grain yield under less irrigation treatment is the result of a significant reduction in number of effective tillers.

Mangan *et al.* (2008) carried out a study to evaluate the performance of yield and yield components traits of wheat genotypes under water stress conditions. Four wheat varieties namely Sarsabz, Kiran-95, TJ-83 (short duration variety) and awn-less variety Local Thori (known to drought-tolerant) were screened under water stress conditions at Nuclear Institute of Agriculture (NIA) Tandojam, during 2003-04. Different irrigation treatments (1, 2, 3 and 4) were applied during various crop growth stages. The experiment was laid out in a Randomized Complete Block Design (Factorial) with four replications. The characters such as number of grains spike^{-1}; main spike yield, 1000-grain weight, biological yield kg ha^{-1}, grain yield kg ha^{-1} and harvest index percentage were recorded. Grain yield and grain yield contributing traits of wheat varieties were significantly affected under water stress conditions. Highly significant difference among both varieties and treatments was observed for number of grains spike^{-1}, 1000-grain weight and harvest index percentage. Except spike yield, Sarsabz had significantly more 1000-grain weight, grain yield, main spike yield and grains spike^{-1} as compared to other varieties over all irrigation treatments; hence more tolerant to drought. Grain yield ranged between 373 kg ha^{-1} in single irrigation treatment to 3931 kg ha^{-1} in four irrigations, whereas 1000-grain weight ranged between 28.1 and 41.8 in four treatments.

Ahmadi *et al.* (2009) carried out a field experiment in 2006-2007 and 2007-2008 to evaluate yield, yield components and water use efficiency of bread wheat in water stress conditions and spraying of desiccant. Main plots were assigned to two levels of water stress treatments; D1: optimum irrigation and D2: cessation of watering from anthesis to maturity stages. Sub plots were assigned to eight bread wheat genotypes; and assimilate limitations with two levels: P1: no source limitation and P2: Inhibitions of current photosynthesis were in sub-sub plots. Grain yield, biological yield, harvest index, the number of grains per spike and 1000-grain weight were significantly influenced by irrigation treatments.

Malik *et al.* (2010) conducted a series of field trials to estimate the effect of number of irrigations on yield of wheat crop in the semi-arid area of Pakistan for three consecutive years from 2005-06 to 2007-08. The study comprised of three treatments including four irrigations (T_1) at crown root development, booting, milking and grain development; five irrigations (T_2) at crown root development, tillering, milking, grain development and dough stage and six irrigations (T_3) at crown root development, tillering, milking, grain development, dough stage and at maturity. The results revealed that during the year 2005-06 and 2006-07 the grain yield and yield contributing parameters were significantly higher when crop was irrigated with T_2, while 1000-grains weight, germination count m^{-2} and number of tillers m^{-2} were not affected significantly during the year 2005-06 and 2007-08. The highest grain yield was recorded with five irrigations at different critical growth stages of wheat crop. The possible reason might be availability of more moisture. The results revealed that the application of irrigation at tillering stage played a vital role to increase wheat yield and contrarily the application of irrigation at maturity caused decrease in wheat yield.

Mishra and Tripathi (2010) conducted a field experiment to study the effect of irrigation frequencies on yield and water use efficiency of wheat varieties during Rabi seasons of 2002-03 and 2003-04. The 12 treatment combinations comprised of four irrigation levels such as I_1 (one irrigation at CRI stage), I_2 (two irrigations: one each at CRI and flowering stages), I_3 (three irrigations: one each at CRI, LT and flowering stages) and I_4 (four irrigations: one each at CRI+LT+LJ+ear head formation stages) along with the combination of three varieties viz., HUW-234, HD-2285 and PBW-154. Progressive increase in number of irrigations from 1 to 4 increased various yield contributing characters such as effective tillers m^{-2}, ear length, no. of grains ear^{-1} and test weight while three and four irrigations were found statistically at par with each other. The highest grain yield (40.65 q ha^{-1}) was credited to I_4 that was significantly superior over I_1 and I_2 but non-significant with I_3.

Moayedi *et al.* (2010a) stated that drought is an abiotic stress affecting the growth and development in plants and its negative effects during the vegetative and reproductive phases of growth causes different changes in the spike characteristics and traits in durum and bread wheat. A study was carried out to compare and evaluate these differences in spike traits in durum and bread wheat genotypes under different irrigation regimes. The experiments were laid out in split-plot arrangement based on a complete randomized block design with three replications at the Mashhad research stations of the Agricultural and Natural Resource Research Center, Iran. Irrigation regimes were considered as the main plots and included four levels, Subplots were assigned to four durum-promising lines and a bread wheat cultivar. The results indicated that the spikelets $spike^{-1}$, potential florets $spike^{-1}$, spike length, spike dry weight, spike partitioning coefficient and spike harvest index significantly decreased under water deficit during floral initiation to anthesis stage. In addition to this, the bread wheat cultivar (Chamran) showed the highest values for spikelets $spike^{-1}$, spike length, spike dry weight, spike partitioning coefficient and spike harvest index compared to durum wheat genotypes.

Rahim *et al.* (2010) conducted a field study in view of the importance of wheat, less available and costly P fertilizer and shortage of water under farmer's field conditions to see the effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. Fertilizer P doses 0, 47, 81 and 111 kg P_2O_5 ha^{-1} were calculated by using adsorption isotherms and applied by broadcast and band placement. Four irrigations i.e. 0, 2, 3, 4 were applied at critical stages of wheat. Basal N:K=130:65 kg ha^{-1} were applied. Wheat grain yield increased from 1.58 Mg ha-1 to 3.94 Mg ha^{-1} with the use of P @ 81 kg P_2O_5 ha^{-1}. Band placement of P proved better over broadcast, whilst three irrigations at crown roots, booting, and grain development stages were sufficient to get maximum yield and improve phosphorus use efficiency.

Sarwar *et al.* (2010) conducted a field study pertaining to the effect of different levels of irrigation on yield and yield components of wheat cultivars during 2005-2006 growing season in Pakistan. Treatments were three cultivars (AS-2002, SH-2002, Aqab-2000), and five irrigation levels: I_1 (irrigation at crown root stage), I_2 (irrigation at crown root + tillering), I_3 (irrigation at crown root + tillering + booting), I_4 (irrigation at crown root + tillering + booting + anthesis), and I_5 (irrigation at crown root + tillering + booting + anthesis + milking). Wheat cultivar AS-2002 recorded highest grain yield (4821.5 kg ha^{-1}) which was significantly higher than the other two cultivars. Wheat crop supplied with five irrigations at crown root + tillering + booting + earing + milking recorded the highest grain yield (5696.8 kg ha^{-1}) which was significantly higher than all the other irrigation levels. At highest irrigation level I_5, cultivars AS-2002 and SH-2002 produced grain yield at par but significantly higher than Aqab-2000. At all the other irrigation levels, cultivar AS-

2002 recorded significantly higher grain yield than the other two cultivars.

Xiao *et al.* (2010) conducted a study to provide reference for the field irrigation management of high yield and quality cultivation of strong gluten wheat. Under field conditions, the effects of irrigation times on nitrogen metabolism and yield of strong gluten wheat cultivar zhengmai 9023 were studied. The results indicated that NR activity, Chlorophyll and nitrogen content in flag leaf increased with irrigation times, and the irrigation treatment had obvious advantages during middle filling stage. Grain protein content showed "V" type change with grain filling going on, and protein content decreased when irrigation times going on. There was significant difference among treatments during early stage of grain filling, and the difference became smaller in the late grain filling stage. The grain yield and protein yield increased but the protein content decreased with increasing of irrigation times. Increasing irrigation times properly could improve grain yield.

Lie *et al.* (2011) stated that the North China Plain (NCP) is one of the main productive regions for winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) in China. However, water-saving irrigation technologies (WSITs), such as sprinkler irrigation technology and improved surface irrigation technology, and water management practices, such as irrigation scheduling have been adopted to improve field-level water use efficiency especially in winter wheat growing season, due to the water scarcity and continuous increase of water in industry and domestic life in the NCP. As one of the WSITs, sprinkler irrigation has been increasingly used in the NCP during the past 20 years. In this paper, a three-year field experiment was conducted to investigate the responses of volumetric soil water content (SWC), winter wheat yield, evapotranspiration (ET), water use efficiency (WUE) and irrigation water use efficiency (IWUE) to sprinkler irrigation regimes based on the evaporation from an uncovered, 20-cm diameter pan located 0-5 cm above the crop canopy in order to develop an appropriate sprinkler irrigation scheduling for winter wheat in the NCP. Results indicated that the temporal variations in SWC for irrigation treatments in the 0-60-cm soil layer were considerably larger than what occurred at deeper depths, whereas temporal variations in SWC for non-irrigation treatments were large throughout the 0-120-cm soil layer. Crop leaf area index, dry biomass, 1000-grains weight and yield were negatively affected by water stress.

Mirzaei *et al.* (2011) did an investigation in order to study the response of grain yield and yield components of bread wheat cultivars to drought stress in western Iran in 2008-2009. The main plots were levels of drought stress (full irrigation, stress at early stem elongation, flowering and grain filling stages) and subplots were five cultivars (Chamran, Dez and Verinak). The results indicated that the effect of drought on grain yield and yield components was significant. Drought stress at all growth stages induced reducing grain yield and yield components. Drought stress at stages of stem elongation, flowering and grain filling stages induced 32 percent, 32 percent and 35 percent reduce in grain yield, respectively. Stress at stem elongation stage had the highest sensitivity than other growth stages. Also, the most and least numbers of spikes/m^2 were observed in full irrigation and Chamran cultivar and in stress at stem elongation stage and Dez cultivar, respectively. As a result, we can use Verinak cultivar for conditions which irrigation is not possible or water deficit occurs in same regions of western Iran.

Shahryari and Mollasadeghi (2011) conducted a study that had been performed in the form of completely randomised block design at two levels of normal irrigation and end drought stress for the purpose of reviewing traits affecting yield and yield components of 20 wheat genotypes. Traits such as days to emergence, days to heading, days to maturity, grain yield, biological yield, harvest index, number of spike per square meter, number of grain per spike, one-thousand grain weight, plant height and spike length and weight were studied. Drought stress resulted in reducing grain yield and its components of all genotypes. Average of traits was meaningfully decreased under drought stress condition. In normal circumstances the most grain yield related to genotype 2 and the lowest grain yield belonged to genotype 1. In drought stress condition, genotypes 25 had the highest grain yield and genotype 37 have the lowest grain yield. Correlation analysis of grain yield with its components showed that in normal irrigation conditions the biological yield and grain yield had d the highest correlation with grain yield, but in drought stress condition, no significant relationship was observed. Accordingly, we can carry out selection of genotypes for high yield in terms of normal irrigation using the traits most correlated with grain yield. So we can consider grain yield and biological yield as the selection criteria of preferred genotypes to breeding end drought tolerance.

Sun *et al.* (2011) reviewed the effects of deficit irrigation on physio-ecological indices of winter wheat at the Luancheng Agro-Ecosystem Experimental Station of Chinese Academy of Sciences. Field plot irrigation experiments had shown that different levels of deficit irrigation at different growth stages of winter wheat affected root size and distribution in the soil profile, canopy structure, biomass growth, grain yield, and water use efficiency. The experiments showed that different levels of deficit irrigation facilitated leaf stomata adjustment which in turn affected the photosynthetic products and distributions of dry matter. The highest grain yield was obtained under optimal deficit irrigations at the different growth stages. This implied that the levels of deficit irrigation were different at different growth stages of winter wheat. The deficit sensitivity index was highest at jointing stage, when was not suitable time for deficit irrigation. In other words, deficit irrigation at other growth stages like the recovering and grain-filling stages little affected grain yield and therefore resulted in high water use efficiency. Based on the above results, an optimal irrigation scheme was developed in relation to the trend in precipitation leveling the region - i.e., one, two and three times of irrigation at about 60-70 mm every time in wet years, normal years and dry years, respectively. The optimal irrigation scheme had been widely used in the North China Plain region.

Wu *et al.* (2011) studied on the effect of compensation irrigation on yield and water-use-efficiency of winter wheat in Henan Province, PR China. The results showed that the soil was obviously short of moisture when the irrigation was managed in the former stage and the layer of 20-40 cm was the lowest one in all of the layers. The volume of spike ha^{-1} and the tiller volume of single plant were improved under the national compensation irrigation. The spike volume ha^{-1}, the tillers and spikes $plant^{-1}$ were increased by 16 500-699 000, 0.12-1.16 and 0.01-0.11, respectively. For the effect on plant height, spike length and grains $spike^{-1}$, the combinative treatment of irrigation in the former stage and medium irrigation compensation at the later stage were better. The wheat yield was increased by 2.54%-13.61% compared to control.

Yang *et al.* (2011) conducted a study to analyse the effects of different irrigation amount on the growth of wheat in arid oasis area and determine effective use measures and reasonable irrigation indices of water in farmlands under arid oasis environment, so as to provide reference for the development and management of water-saving technology. Spring wheat in different growth periods was irrigated for four times. The leaf area index, dry matter content, 1000-grain weight of wheat in different growth periods and water use efficiency within the growth period were measured. Booting stage, heading stage and flowering stage were water sensitive stages and the irrigation amount was not lower than 60 percent of total irrigation quantity. Four times of irrigation in the whole growth period were appropriate. The appropriate water deficiency was conducive to irrigation and increase in water use efficiency. The inadequate water supply would worsen the water loss in deep layer of soil. When the irrigation quantity increased to a certain extent, wheat yield would not increase with irrigation quantity. The study found that 6,000 mm irrigation amount per 1 hm^2 could be an optimisation index of irrigation for spring wheat in arid oasis area.

Kumar *et al.* (2013) conducted a field experiment during winter seasons of 2003-04 and 2004-05 to study the effect of irrigation and fertilizer management on yield and economics of simultaneous planting of winter sugarcane and wheat. The experiment was carried out in split plot design, keeping four irrigation options in main plot, such as irrigation scheduled at 0.8 (I_1), 1.0 (I_2), 1.2 (I_3) IW/CPE ratio and critical stages i.e. crown root initiation, tillering, late jointing, flowering, milk and dough stages of wheat (I_4), and four nutrient levels, viz. 100% (F_1), 125% (F_2), 150% (F_3) and 175% (F_4) of nutrient levels with four replications (100% recommended dose of nutrient means 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1}). Maximum cane germination (35.3%) was noticed under treatment having irrigation at physiological stages of wheat, which was

3.9 to 5.5 percent higher over the 0.8 and 1.0 IW/CPE ratio irrigation regimes. Shoot height (379.3 cm), dry matter accumulation (199.4 g $shoot^{-1}$), number of millable cane (94.41 thousand ha^{-1}), cane yield (83.85 t ha^{-1}) and green top yield (12.93 t ha^{-1}) were also maximum under plot irrigated at important physiological stages of wheat crop. The application of 175 percent of recommended NPK fertilizer cane and wheat yields were 8.4 to 12.7 percent and 16.4 to 31.9 percent higher as compared to 125 and 100 percent recommended NPK, respectively. Application of 175 percent recommended dose of nutrients resulted significantly higher nitrogen uptake (223.9 kg ha^{-1}), phosphorus uptake (27.7 kg ha^{-1}) and potassium uptake (288.9 kg ha^{-1}) than that of 100, 125 and 150 percent recommended NPK. The maximum gain of gross return (Rs 126,992.0 ha^{-1}), net return (Rs 75,882.5 ha^{-1}) and B:C ratio (1.49) was obtained with irrigation at physiological stages of wheat followed by irrigation at 1.2 IW/CPE ratio over the irrigation at 0.8 and 1.0 IW/CPE ratio whereas, least net returns (Rs 48,687.4 ha^{-1}) and B:C ratio (1.34) was under 0.8 IW/CPE ratio. Crop fertilised with 175 percent recommended dose of nutrient gave highest gross return (INR 130,938 ha^{-1}), net return (INR 79,067.4 ha^{-1}) and B:C ratio (1.53) over 100 percent and 125 percent recommended dose of nutrients. This indicates that application of 175 percent recommended NPK (210 kg N, 105 kg P_2O_5 and 70 kg K_2O ha^{-1}) and irrigation at critical stages of wheat is sufficient to provide nutrients for higher yield and economics of simultaneous planting of sugarcane and wheat in Tarai region of Uttarakhand.

Ngwako and Mashiqa (2013) studied the effect of irrigation on the growth and development of winter wheat cultivars. The experiment comprised of two cultivars of wheat, namely Baviaans, and 14SAWYT306; four levels of irrigation namely: I_0 = no irrigation, I_1 =

irrigation up to stem extension, I_2 = irrigation from stem extension up to physiological maturity, and I_3 = irrigation throughout the growth stages. Significant difference in the cultivars was observed in the days to emergence, days to anthesis, number of tillers and number of grains spike^{-1}. Cultivar 14SAWYT306 took long to emerge and flower but matured at the same time as cultivar Baviaans. Cultivar Baviaans produced higher leaf area index, leaf dry mass, stem dry mass and more tillers than 14SAWYT306. More grains spike^{-1}, grain yield, harvest index and grain protein were recorded in cultivar 14SAWYT306. Irrigation significantly affected days to maturity, number of tillers, number of grains spike^{-1} and grain yield. Irrigation throughout the growth stages increased number of tillers, number of grains spike^{-1}, grain yield, harvest index and grain protein by 20.58%, 26.07%, 42.72%, 16.71% and 3.31%, respectively over no irrigation.

Shirazi *et al.* (2014) carried out a field experiment to evaluate the effect of irrigation regimes and nitrogen levels on the growth and yield of wheat cv. Kanchan (*Triticum aestivum* L.). The experiment includes two factors such as four irrigation regimes and four nitrogen levels. Three farmer's fields were selected for experimentation as replication. Yield and yield contributing factors were significantly affected by irrigation regimes and different doses of nitrogen. Maximum grain yield of 2.27 t ha^{-1} by the application of 200 mm irrigation treatment. Meena *et al.* (2015) conducted an investigation for two consecutive *Rabi* seasons of 2011-12 and 2012-13 at Research Farm of the Indian Institute of Wheat and Barley Research, Karnal (Haryana) to study the effect of hydrogel (synthetic Poly Acryl Amid) on *in situ* moisture conservation under different nutrient and irrigation levels. The experiment was conducted in split plot design with three main plot treatments (no irrigation, two irrigations and four irrigations) and six sub-plot treatments (100% NPK without hydrogel, 100% NPK with 2.5 kg ha^{-1} hydrogel, 100% NPK with 5 kg ha^{-1} hydrogel, 70% NPK without hydrogel, 70% NPK with 2.5 kg ha^{-1} hydrogel, 70% NPK with 5 kg ha^{-1} hydrogel). Progressive increase in wheat grain yield was recorded with every increment in irrigation level and four irrigations brought about significantly higher grain yield (44.82 q ha^{-1}) over no irrigation (32.37 q ha^{-1}) and two irrigations (42.03 q ha^{-1}). No yield improvement was observed with hydrogel application. The difference among various hydrogel treatments were found statistically at par. Grain yield was the highest under 100 percent of recommended dose of NPK with (40.26 q ha^{-1}) and without (41.14 q ha^{-1}) hydrogel. On pooled basis 70 percent NPK application with and without hydrogel recorded significantly lower yield than 100 percent NPK application.

2.1.3 Effects of irrigation on biochemical attributes and water relation

Chetal *et al.* (1982) studied the chemical composition of wheat and barley leaves under water stress. They grew wheat cultivars S-308 and C-306 and barley cultivars BG-25 and C-138 during the winter season under water stress imposed by withholding irrigation at the tillering, ear emergence and grain filling stages. Chlorophyll contains of the leaves of both wheat and barley cultivars were decreased by water stress applied at all the growth stages. Effects were most marked at the grain filling stage. They also noticed that the effects of water stress on leaf chemical composition of both wheat and barley cultivars.

Ashraf *et al.* (1994) worked on the effect of water stress on chlorophyll content in wheat. They reported that water resulted in reduced chlorophyll a, chlorophyll b and total chlorophyll content. A series of experiments was carried out on both water stress tolerant and susceptible wheat cultivars to drought induced by PEG-6000 solutions. They also noticed that chlorophyll a:b ratio increased under water stress condition and the effect was more pronounce in water stress susceptible cultivars.

Rahman and Paul (1998) studied the effect of soil moisture regimes on water relation characters, chlorophyll contents and grain yield of two wheat cultivars – Akbar and Barkat in the field condition. The highest RLWC of both the cultivars was observed at 8:00 am and it decreased gradually at the later part of the day. RLWC was higher in the irrigated than in the rain-fed plants.

Sarker *et al.* (1999) stated that the rain-fed plants had consistently lower RLWC. The RLWC values of the irrigated plants were significantly higher in the morning but lower values were found at noon, showing some recovery in the afternoon.

Chandrasekar *et al.* (2000) conducted an experiment to investigate the phenological and bio-chemical response of two hexaploid and two tetraploid wheat genotypes to water stress under pot culture condition. Water stress caused a decline in relative water content in all the genotypes. Both the tetraploids and hexaploids showed a lower reduction in relative water content under water stress. They also reported that water stress decline chlorophyll content of both hexaploids (*Triticum aestivum*) and (*Triticum dicoccum* and *Triticum durum*) wheat leaves.

Paul *et al.* (2002) conducted a field study in Rajshahi, Bangladesh on eight cultivars of wheat showed that irrigated plants had higher RLWC and chlorophyll content compared to rain-fed plants.

Haider and Paul (2003) studied physio-biochemical responses of four bread wheat cultivars under three different water regimes in field condition over two *Rabi* seasons. Water stress decreased RLWC and chlorophyll a and b contents but increased chlorophyll a:b ratio.

2.2 EFFECTS OF MULCHING

2.2.1 Effects of mulching on the growth and physiological attributes

Ha *et al.* (1985) found that mulching increased soil temperature and moisture during winter resulting in more rapid crop growth, especially at the maximum tillering and culm internodes differentiation stages. Mulching also increased leaf area until booting, number of spikes m^{-2} and grains $spike^{-1}$ and accelerated heading and maturity by 7-9 and 3-7 days, respectively. Grain yield increased by 56 percent in wheat and 39 percent in barley by mulching after drilling, compared with conventional row sowing and no mulch.

Sharma and Chakor (1989) reported from a series of field trial in 1980-82 in the hill region, wheat cv. S308 and VL 421 sown in the first week of November, December or January gave average grain yields of 2.91, 2.14 and 1.38 t ha^{-1} in 1980-81 and 4.0, 3.34 and 1.83 t ha^{-1} in 1981-82, respectively. Mulching with pine accedes at 1 kg m^{-2} increased plant height, the number of effective tillers $plant^{-1}$ and leaf area index (LAI), minimised soil temperature and gave yields of 2.45-3.35 t ha^{-1} compared with 1.83-2.76% t ha^{-1} without mulching.

Naresh *et al.* (1997) conducted a series of field experiments in the winter seasons of 1990-92 on silt clay loam soil at Palampur, Himachal Pradesh in India. The study demonstrated that 30 t ha^{-1} of green *Lantan caniara* mulch decreased the days to maturity of wheat cv. VL 616 and increased growth, yield components and grain yield.

Angbabu *et al.* (2007) carried out an experiment in West Bengal, India to study the growth and productivity of wheat (*Triticum aestivum* cv.HP 1731) as influenced by the different levels of evapotranspiration control measures. They showed that the combined application of straw mulch at 6 t ha^{-1} + kaolin spray at 6.0% w/v significantly influenced leaf area index (LAI), dry matter accumulation (DMA), crop growth rate (CGR), net assimilation rate (NAR) and yield during both the years of 2000-01 and 2001-2002.

2.2.2 Effects of mulching on the yield and yield components

Prihar *et al.* (1979) noticed that mulching increased storage, particularly in the upper soil layers, and increased wheat yields from 1.9 to 2.25 t ha^{-1} after maize and 2.91 to 3.33 t ha^{-1} after follow cropping pattern.

Bakajev *et al.* (1980) reported the effect of straw mulch, applied annually at the rates of 0, 1, 2, 4 and 8 t ha^{-1}, in 1967-1978 during three complete cycles of four course rotation "Summer fallow three times spring wheat". Under the semi-arid Steppe conditions of Northern Kazakhstan, mulching of the calcareous silty clay loam Southern Chernozem soil resulted in the greater accumulation of plant available moisture and reduced soil temperature.

De *et al.* (1983) stated that in field experiments on wheat for two-year showed a beneficial effect of organic mulch (rice straw), by decreasing the evapotranspiration (ET) losses of soil water, increasing grain yield. Increase in grain yield might be due to decreased late tiller survival, longer ears and greater spikelet fertility. The number of shriveled grains ear^{-1} was reduced by ET control measures.

Zhang (1984) observed that dry matter (DM) yield in the mulched plots increased by 71.5 percent. Plant height with mulch was 92.5 cm compared with 86.1 cm for controls. Matched plants had larger ears and more grains panicle^{-1} resulting in significantly higher yields.

Khan (1989) stated that the influence of tillage methods in association with vertical mulches (sand and saw dust) was studied on the conservation of soil moistures its utilisation and yield of gram and wheat grown on vartisol under rain-fed conditions. Deep tillage with mulching conserved soil moisture and its efficient use increased the yields of wheat.

Sharma *et al.* (1990) observed in two filed trials on sandy loam soil, that maize stalk mulch conserved more soil moisture than did the fallow control or repeated ploughings and plankings. A Sal leaf (*Shorea robusta*) mulch at 10 t ha^{-1} was as effective as maize stalk mulch. Furthermore, maize stalk mulch, with or without tillage, conserved 35.6 and 63.6 mm more moisture/450 mm soil than deep tillage treatments and fallow control in 1986-87, between maize harvest and sowing of wheat. Mulch induced residual soil moisture significantly increased the grain and straw yield of rain-fed wheat.

Ning and Hu (1990) found that in a field trial in Hubei province, PR China that 3 t rice straw ha^{-1} spreaded uniformly after sowing increased wheat yields by an average of 0.32 t ha^{-1} (12%) with 150 kg N and 75 kg P_2O_2 ha^{-1} and rice straw increased wheat yield from 0.79 to 1.35 t ha^{-1}.

Sandhu *et al.* (1992) reported that dry land wheat cv. WL 410 was mulched with 4.0 t rice straw ha^{-1}, 4.0 t *Prenna rmucronata* leaves and twigs ha^{-1} or not mulched. Four tonnes *Prenna rmucronata* leaves and twings ha^{-1} increased soil NO_3 –N at wheat sowing, N application increased wheat yield in five out of six years. Four tonnes *Prenna* *rmucronata* leaves and twings ha^{-1} always had a greater effect than mulch with 4.0 t rice straw ha^{-1}. Mulching only affected yield in the year especially when rainfall was low.

Sharma and Thakur (1992) reported that a series of field trails in the rabi season of 1982-85 at Palampur, India wheat cv. VL was sown at 75, 100 or 125 kg seed ha^{-1} in rows 22 or 30 cm apart with or without 8 t dust or straw mulch ha^{-1} and find out that the average grain yield was unaffected by sowing rates or row spacing but increased by the straw mulch giving a yield of 1.5 t ha^{-1} compared with 1.15 t ha^{-1} from the control; but the dust mulch had no significant yield advantage over the control (no mulch).

Misra (1996) stated that soil mulching increased the availability of conserved moisture in the soil profile and significantly enhanced growth and grain yield (plant height, spike weight, spikelets spike^{-1}, grains spike^{-1} and the number of effective tillers plant^{-1}) of wheat cv. Meghdoot (*Triticum durum*) and Sujata (*T. aestivum*) under rain-fed condition.

Chen *et al.* (1996) observed that the effects of rice straw mulching under wheat-maize rotation system on soil fertility and crop yields in 1990-91. The results showed that mulching with rice straw under wheat-maize rotation significantly increased the yields of crops. Compared with the control, the range of crop yields increased 6.69-25.86 percent.

Upadhyay and Tiwari (1996) reported in a field experiment where wheat cv. Sonalika and Loki were mulched with 10 t rice straw, 5 t sawdust ha^{-1} or soil; mulched. Mulching with rice straw along with 120 kg. N and 150 kg seed ha^{-1} produced the heigher grain yield.

Parmer and Sharma (1996) conducted a research study to access the effects of different levels of P (0, 26, 52 and 78 kg ha^{-1}) and various mulching materials (no mulch, *Pinus longifolia, Lantana camara* and polythene), no nutrition uptake (N, P and K) and the productivity of wheat for two consecutive winter seasons. Nutrient uptake and dry matter yield of wheat at tillering and flowering stages, and also the grain and straw productivity of wheat at all the growth stages, averaged over P levels. Yield was the highest (3.221 t ha^{-1}) with polythene mulch.

Du *et al.* (1997) reported that spring wheat was bunch-planted and mulched with plastic film throughout the growing season or form sowing the three-leaf stage of plants (T_2) or bunch-planted or drilled on the open ground without mulching (T_3 and T_4) and result out that compared with the other three treatments, increased the moisture and accumulated temperature of the ground, improved aeration and other physical properties of the soil, and facilitated the mineralisation of organic matter in the soil and the uptake of the N and P by the plants. Moreover, mulched with plastic film reduced the duration from sowing to-emergence, advanced tillering, young spike differentiation, seed formation and seed filling lengthened grains $spike^{-1}$ and 1000-grain weight and improved biomass and economic yield.

Sharma *et al.* (1998) observed that the effect of level and timing of incorporate on Leucaena leaf mulch on soil water use performance of wheat grown on Dhootkot silty clay loam soil in sub-montane Northwest India. Air dried leucaena leaves were applied as a surface mulch at the rate of 0 (no mulch), 2, 4 and 6 t ha^{-1}. The application of mulch increased moisture extraction, grain and straw yield of wheat.

Wang *et al.* (2000) studied yield effects of collecting rainwater and water-saving irrigation on film-mulched winter wheat and corn in dryland in different years.

Sharma *et al.* (2001) showed that the application of mulch reduced soil moisture losses by checking evaporation between the period of maize harvesting and wheat sowing. More soil moisture was available in the surface layer (0-15 cm) at the time of wheat sowing, which was helpful in increasing the number of wheat plants emerged per meter row length. The application of mulch increased wheat grain and straw yield significantly. The study indicated that the application of leucaena leaf mulch at 2 t ha^{-1} and its incorporation at 30 days after maize harvest was beneficial for conserving soil moisture, improving seed germination and productivity of rain fed wheat.

Xue *et al.* (2002) showed that straw mulching techniques result in higher soil moisture and yield within a short period. However, straw mulching can increase the contents of organic and soil water which will result in a good cycle of sustainable development in arid land farming.

Zhang *et al.* (2002) stated that, compared with no irrigation, irrigating 30 mm had a great effect on the yield of spring wheat (*Triticum aestivum*) with plastic film mulching. During the jointing stage, 30 mm irrigation increased yield by 371.1 kg hm^{-2} and water use efficiency by 11.2 percent. Taking precipitation distribution into consideration, the jointing stage is the best water-supplementing period of rain-collecting and water-saving irrigation of spring wheat with plastic-film mulching. Approximately 30, 60, 90 and 120 mm irrigation water at one irrigation increased the grain yield by 23.4, 68.7, 105.5 and 98.3 percent, and water use efficiency was raised by 16.3-67.2 percent. Irrigation efficiency is 16.1, 21.6, 22.1 and 15.43 kg mm^{-1} hm^{-2}, respectively. Thus, the optimal irrigation amount of spring wheat with plastic-film mulching is 60 mm at one time.

Liao *et al.* (2003) showed that double mulch and film plus straw during summer season fallow period could collect rainfall to the utmost extent and over 73.2 percent of this moisture could be stored in soil, which is 108.4 mm more than using conventional tillage. Furthermore, it could not only conserve water stored in soil but could also collect rainfall during the growth period as much as by using ridges plus film mulch and furrow sowing. The results also showed that double mulch of film and wheat straw during summer fallow obtained the highest wheat yield compared to the other treatments.

Wang *et al.* (2004) conducted a field experiment in the manural Loessial soil in the middle of Shaanxi, China, a sub-humid area prone to drought, to study the effects of rainwater-harvesting cultivation on water use efficiency (WUE) and yield of winter wheat. Ridge-furrow tillage was used. The ridge being mulched by plastic sheets for rainwater harvesting while sowing in the furrows. From the sowing to reviving stage of winter wheat, water stored in 0-100 cm layer significantly decreased whereas that in 100-200 cm layer did not change. Compared to non-mulching, plastic sheet-mulching retained 6.5 mm more water as an average of the two N rate treatments, having a certain effect on conservation of soil moisture. In contrast, at harvest, water was remarkably reduced in both the 0-100 and 100-200 cm layers, and mulched plots consumed 34.8 mm more water as an average of the two treatments: low N rate (75 kg N ha^{-1}) with low plant density (2,300,000 plants ha^{-1}) and high N rate (225 kg ha^{-1}) with high plant density (2,800,000 plants ha^{-1}), in 0-200 cm layer than those without mulching, the former being beneficial in the utilisation of deep layer water. Mulching was significant in harvesting water and in increasing yield. Mulched with plastic sheets, biological and grain yields were 22.5 and 22.6 percent higher for the average of the high N rate than for the low N rate. The high N rate with low plant density was 29.8 and 29.1 percent higher in both biological and grain yields than that of the low N rate with low plant density. With high N rate and high plant density, the mulched biological and grain yields were 39.5 and 28.9 percent higher than the corresponding treatments without mulching. The treatments with high N rate and low plant density had the highest in both biological and grain yields, and the water use efficiency reached 43.7 kg mm^{-1} ha^{-1} for biological yield and 22 kg mm^{-1} ha^{-1} for grain yield.

Du *et al.* (2005) conducted a study to determine the effect of water supply regimes and plastic-film mulching on the harvest index (HI), reproductive allocation (RA), and the range of size inequalities in spring wheat (*Triticum aestivum*) populations, and to explore the mechanisms causing them. Grain yield, biological yield, HI, and RA of spring wheat decreased significantly ($P<0.001$) along the irrigation gradient (applied water decreased from 0.35 to 0.175 to 0 m^3 m^{-2}). Either mulched or non-mulched, the range of size inequalities always increased. HI and RA in the mulched treatment were significantly lower than in the non-mulched treatment ($P<0.05$). Results suggest that the range of size inequalities in spring wheat populations are closely correlated with the water regime in the field, and that under greater drought stress there are relatively smaller plants with lower HI. A greater range of size inequalities may result in growth redundancy. Appreciable growth redundancy occurred in spring wheat populations mulched with plastic film, which may result from the exacerbated interplant competition and self-thinning. Thus, spring wheat cultivation with plastic-film mulching was not the best method, although grain yields increased 38.5 percent in mulched treatments compared with non-mulched control plots.

Rahman *et al.* (2005) conducted a field experiment at the research farm of the Wheat Research Centre, Dinajpur, Bangladesh, to evaluate rice straw as mulch for no-till wheat. Rice straw mulching had a significant effect on conserving initial soil moisture and reducing weed growth of weed flora, promoting root development and thereby improved grain yield of no-till wheat.

Sharma *et al.* (2005) reviewed the effects of tillage and mulching on moisture conservation and nutrient use in the maize-wheat cropping system. The field studies at different locations of this region have shown the beneficial effects of resource conserving technologies for improving productivity of maize and following wheat. The results have suggested that the conventional repetitive tillage operations including deep ploughing can be dispensed with, and equally good or even higher yields can be obtained with minimum or zero tillage along with mulching or residue management practices over a period due to improved soil environment. Live mulching with weeds, annual legumes or pruned biomass of perennial legumes in alley cropping systems are beneficial for efficient conservation of soil, moisture and nutrients for higher productivity in maize-wheat cropping system.

Xie *et al.* (2005) conducted the field experiments to study the evapotranspiration (ET), evaporation (E), growth, yield and water use efficiency (WUE) of plastic-mulched spring wheat with hole planting in 1990 and 1991 under full and deficit irrigation at Zhangye Station of Water-saving Agriculture, Gansu Academy of Agricultural Science in northwest China. The experiment was designed to maintain minimum soil water content (MSWC) to different levels: 85%, 70%, 60%, 50% and 40% of field capacity in rooting depth and treatment to be non-irrigation. The treatments were laid out in a randomized complete block with four replications, and a non-mulched replication as control. The study indicated plastic mulched had higher ET than non-mulched due to increase of LAI. Seasonal ET was 269 mm for the plastic-mulch treatments with MSWC 40 percent and 765 mm with MSWC 85 percent, increased 19.8 percent and 2.0 percent than non-mulched, respectively. The ET rates of mulch treatments were lower before tillering, and higher after tillering. Plastic mulching could decrease evaporation from soil by 55 percent in comparison with non-mulched for the treatment of 60 percent MSWC. The yield was the highest with treatment of MSWC 60 percent in 1990 and 70 percent in 1991, and it was significantly higher than treatments of MSWC 40 percent and non-irrigation. However, there were not significant differences in yield when MSWC were between 50 percent and 85 percent. The water use efficiency (WUE) of the plastic-mulched treatment reduced with the increase in MSWC. They were 0.86 kg m^{-3} for the treatment of MSWC 85 percent in 1990 and 0.89 kg m^{-3} in 1991, significantly lower than MSWC 40-60 percent and non-irrigation. There were increases of 0.9-30.8 percent in ET and 4.0-110.3 percent in yield for all plastic-mulched treatment over non-mulch. The WUE with plastic mulch was 2.0-61.0 percent higher than non-mulch, and the difference increased with the decreasing of MSWC. The net seasonal income, benefit-cost ratio and net profit per mm of water used were bigger compared with non-mulched under less than 60 percent MSWC, however they became smaller from 60 percent up to 85 percent. Finally, the results revealed that spring wheat mulched with plastic maintained higher WUE and net income than non-mulched under low soil water content, which makes it suitable for deficit irrigation in arid circumstance.

Zhang *et al.* (2005) stated that maize (*Zea mays*), a staple crop grown from June to September during the rainy season on the North China Plain, is usually inter-planted in winter wheat (*Triticum aestivum*) fields about one week before harvesting of the winter wheat. In order to improve irrigation efficiency in this region of serious water shortage, field studies at Luancheng Experimental Station in 1999 and 2001, two dry seasons with less than average seasonal rainfall, were conducted with up to five irrigation applications to determine evapotranspiration, calculate the crop coefficient, and optimize the irrigation schedule with maize under mulch, as well as to establish the effects of irrigation timing and the number of applications on grain yield and water use efficiency (WUE) of maize. Results showed that with grain production at approximately 8000 kg ha^{-1} the total evapotranspiration and WUE of irrigated maize under mulch were approximately 380-400 mm and 2.0-2.2 kg m^{-3}, respectively. Also in 2001 WUE of maize with mulch for the treatment with three irrigations was 11.8 percent better than that without mulch. In the 1999 and 2001 seasons, maize yield significantly improved (P=0.05) with four irrigation applications, however, further increases were not significant. At the same time there were no significant differences for WUE with two to four irrigation applications. In the 2001 season mulch lead to a decrease of 50 mm in the total soil evaporation, and the maize crop coefficient under mulch varied between 0.3-1.3 with a seasonal average of 1.0.

Eneji *et al.* (2008) studied soil water conservation and physiological growth of wheat (*Triticum aestivum* L.) using composted cattle manure applied either as mulch or incorporated with soil at 20 Mg ha^{-1}. Haruhikari, a relatively drought-sensitive and Hongmangmai, a relatively drought-tolerant wheat, were the cultivars studied under both adequate and deficit irrigations. Fourteen weeks after sowing (WAS), the number of tillers and leaves was significantly reduced by 19 percent and 30 percent respectively under deficit irrigation and Hongmangmai produced slightly (10%) more tillers than Haruhikari. Unlike mulching, the incorporation of manure had favourable effects on plants in terms of shoot dry mass (SDM) by 36 percent and number of tillers and leaves by 40 percent. Haruhikari produced substantially (29%) greater root mass under adequate irrigation but Hongmangmai produced slightly (2.7%) more roots and responded much better to manure use whether under adequate or deficit irrigation. As a result, Hongmangmai suffered less severe reductions in tillers and biomass under water stress. In comparison, the mulched manure treatment saved 15 percent and 64 percent respectively more water than the control.

Ma *et al.* (2010) conducted a field experiment in Jurong of Nanjing, Jiangsu Province, PR China from 2006 to 2008. The study was designed to have four treatments: no rice straw applied (CK), rice straw burnt in situ (RB), rice straw evenly incorporated into the topsoil (RI) and rice straw evenly spread over the field as mulch (RM). The results showed that the wheat grain yield in treatment RI was 1.0-1.2 times that in the treatment CK. Based on these results, the best management practice of returning rice straw to the soil prior to wheat cultivation is evenly incorporating rice straw into the topsoil, as the method tended to reduce NO_2 emission during the wheat-growing season and increase wheat yield and soil fertility.

Sharma *et al.* (2010) conducted a field experiment at Dehradun in India during 2001 to 2004 to study the effect of in situ grown live mulching with legumes such as Sunnhemp (*Crotalaria juncea* L.), Dhaincha (*Sesbania aculeata* Pers.) and Cowpea (*Vigna unguiculata* L. Walp.), besides weed mulching at 30 and 45 days of maize (*Zea mays* L.) growth on moisture conservation, crop productivity and soil properties in maize-wheat (*Triticum aestivum* L. emend Fiori & Paol.) cropping system.

Legume mulching accumulated 1.09-1.17 t ha^{-1} dry biomass and added 27.9-31.3 kg N ha^{-1} compared with 1.31 t ha^{-1} biomass and 10.3 kg N ha^{-1} with weed mulching at 30 days; which increased further by 68.5-74.8 percent when applied at 45 days. Wheat yields increased by 13.3-14.0 percent due to legume mulching in previous maize following enhanced soil moisture and nutrient conservation. Mulching with weed biomass was inferior to legume mulching in both the crops.

Singh *et al.* (2010) stated that soil evaporation is considered to be a non-productive component of evapotranspiration (ET). Measures which moderate soil evaporation may influence the amount of water available for transpiration, the productive component of ET. Field experiments investigating the effect of rice straw mulch on components of the water balance of irrigated wheat were conducted during 2006-07 and 2007-08 in Punjab, India, on a silt loam soil. Daily soil evaporation (Es) was measured using mini-lysimetres, and total seasonal ET was estimated from the water balance equation using measurements of irrigation, rainfall and soil water depletion. The mulch lowered total soil evaporation over the crop growth season by 35 and 40 mm in relatively high and low rainfall years, respectively. Much of this "saved water" was partitioned into transpiration, which increased by 30 and 36 mm in the high and low rainfall years, respectively. As a result, ET was not affected by mulching in either year. This is a very important finding in relation to the potential for mulching to save water and increase WPET. In both years, there was significantly higher tiller survival and grain weight with mulching, and this led to significantly higher grain and total biomass yields in 2006-07, probably because the non-mulched treatment suffered from water deficit stress for a period after maximum tillering that year. Transpiration water productivity with respect to grain yield was 18.8-19.1

kg ha^{-1} mm^{-1} in 2006-07, and 14.6-16.1 kg ha^{-1} mm^{-1} in 2007-08. There was trend for mulch to lower transpiration water productivity, significantly in 2007-08. The results suggest that while mulching of well-irrigated wheat reduces soil evaporation, it does not "save" water because the crop compensates by reduced transpiration efficiency.

Singh *et al.* (2011a) reported that the retention of rice residues as a surface mulch could be beneficial for moisture conservation and yield, and for hence water productivity, in addition to reducing air pollution and the losses of soil organic matter two field experiments were conducted in Punjab, India, to study the effects of rice straw mulch on wheat growth, yield, water use and water productivity during 2006-2008. Mulching increased soil water content and this led to significant improvement in crop growth and yield determining attributes where water was limiting.

Singh *et al.* (2011b) conducted a field experiment at Selakui, Dehradun during 2001-04 to study the effect of tillage (conventional and minimum) and mulching practices (no mulching and live mulching) under artificially created varying land slopes (0.5, 2.5, 4.5 and 9.5%) on soil-moisture conservation, productivity and nutrient uptake in maize (*Zea mays* L.)-wheat (*Triticum aestivum* L. emend Fiori & Paol.) cropping system. Sunnhemp (*Crotalaria juncea* L.) intercropped with maize gave 0.87-1.09 tonnes biomass (dry weight) and accumulated 24.8-31.4 kg N ha^{-1} at 30 days of growth when it was mulched. Biomass and N accumulation generally decreased with increasing land slope and under minimum tillage. Maize performed better on moderate slopes (2.5-4.5%) than on the relatively flat (0.5%) and highly sloping land (9.5%). However, the yield of wheat decreased linearly and significantly with increasing slope due to less conservation of soil moisture on sloping lands during the previous rainy season. Conventional tillage gave significantly higher productivity of both maize and wheat than the minimum tillage. Intercropping of maize with sunnhemp and spreading the cut biomass as mulch at 30 days (live mulching) improved soil moisture conservation at maize harvest (+1.63 to 1.94%), and yield of maize (12.0%) as well as of following wheat (13.8%) compared with the no mulching.

Qamar *et al.* (2015) argued that zero tillage along with the application of mulch is an important strategy for soil conservation which maintains sustainability of agricultural system. A randomised complete block design in a split plot arrangement was used with four tillage methods [conventional tillage (CT), deep tillage (DT), zero tillage with zone disc tiller (ZDT) and happy seeder (HS)] in main plots and five mulch materials [no mulch (M_0), rice straw (M_R), wheat straw (M_W), plastic sheet (M_P) at 4 t ha^{-1} and natural mulch (M_N)] in subplots during 2009-10 and 2010-11. The results showed that DT significantly decreased soil bulk density, penetration resistance, and volumetric moisture content when compared with CT, ZDT, and HS. However, wheat yield parameters such as germination count, fertile tillers and grain yield were significantly higher in HS compared with other tillage treatments while root length and grain protein were higher in DT. Plant height remained non-significant during 2009-10, while in 2010-11 it differed significantly and was higher in HS than other tillage treatments. Wheat yield parameters were significantly higher in M_P at 4 t ha-1 than other mulch materials. HS and DT along with M_P have positive impact on soil physical properties, root growth and yield parameters by creating a favourable soil environment.

Zhang *et al.* (2015) stated that the soil water supply is the main factor that limits dryland crop production in China. In a three-year field experiment at a dryland farming experimental station, we evaluated the effects of various straw mulch practices on soil water storage, grain yield, and water use efficiency (WUE) of winter wheat (*Triticum aestivum*). Field experiments were conducted with six different mulch combinations (two different mulch durations and three different mulch amounts): high (SM_1; 9000 kg ha^{-1}), medium (SM_2; 6000 kg ha^{-1}), and low (SM_3; 3000 kg ha^{-1}) straw mulch treatments for the whole period; and high (SM_4), medium (SM_5) and low (SM_6) straw mulch treatments during the growth period only, where the control was the whole period without mulch (CK). Throughout the whole growth period of the three-year experiment, the average soil water content in the 0–200 cm soil layer increased by 0.7–22.5 percent compared with CK, while the WUE increased significantly by 30.6%, 32.7% and 24.2% with SM_1, SM_2, and SM_3, respectively ($P < 0.05$). The yield increased by 13.3–23.0 percent when mulch was provided during the growth period, while the WUE increased by 15.2%, 17.2% and 18.0% with SM_4, SM_5, and SM_6, respectively, compared with CK.

2.2.3 Effects of mulching on biochemical attributes and water relation

Roy and Singh (1983) reported from a field trial at Bihar, India in rain-fed wheat, mulches reduced the loss of moisture through evapotranspiration. The moisture use efficiency was highest under polythene mulch followed by straw, stubble and no mulch.

Hou *et al.* (2006) reported that the two mulch treatments increased the photosynthesis rate after 1400 h. The two mulch treatments increased the photosynthesis rate.

Kumar *et al.* (2009) conducted a field experiment during 1993-94 and 1994-95 on rain-fed maize-wheat sequence in mid-hills of Himachal

Pradesh for in situ moisture conservation in standing maize to ensure early establishment of wheat by evading the low moisture regimes at normal sowing dates. Conventional tillage alone or in combination with FYM or mulch and deep tillage with same combinations tested for the purpose showed that deep tillage, farm yard manure and mulch as combined treatment maintained higher soil water content, moderated soil temperature, increased root weight density and improved relative leaf water content (RLWC) in both maize and wheat. Deep tillage, mulch and FYM not only reduced the crop growth period but also improved the crop yields.

2.2.4 Effects of mulching on other crops

Hallidri (2001) investigated the effects of mulching materials on the growth, yield and quality of parthenocarpic cucumber (SHEKULLI F < sub > 1 </ sub > hybrid) grown in an unheated plastic house. The mulching materials were black film, silver film, wheat straw and transparent film. Plant height and number of leaves were significantly affected by the type of mulching although no significant differences were found between mulching materials on stem diameter. The highest plant height and number of leaves were observed on the cucumber mulched with black film, followed by transparent film, silver film, wheat straw and control. Cucumber mulched with transparent film recorded the highest stem diameter, followed by black film, silver film, control and wheat straw. There was no significant difference between large, medium and small fruits in all the treatments. The highest yield within 30 first days was obtained at the black film mulching treatment and the lowest was recorded from the control. Soil temperature at 10 cm depth showed that black film mulching treatment had the highest temperature reading compared to silver film, transparent film, control and wheat straw with average temperature reading of 24.3, 23.8, 22.9, 22.01 and 22.5 degrees C, respectively. At 30 cm depth, the black film mulching treatment had the highest average soil temperature, followed by silver film, transparent film, control and wheat straw with average soil temperature reading of 23.17, 23.16, 22.86, 22.31 and 21.43 degrees C, respectively.

Hulugalle *et al.* (2001) stated that many cotton growers sow rotation crops after irrigated cotton (*Gossypium hirsutum*), assuming that they will improve soil quality and maintain profitability of cotton. Wheat (*Triticum aestivum*) is the most common rotation crop, although more recently, legumes such as faba bean (*Vicia faba*) and chickpea (*Cicer arietinum*) have come into favour. This paper reports data on soil quality (organic C, nitrate-N, soil structure), yield (cotton lint and rotation crop grain yield, fibre quality), economic returns (gross margins ha^{-1}, gross margins/ ML irrigation water), and management constraints from an experiment conducted from 1993 to 1998 near Wee Waa, north-western New South Wales, Australia. The soil is a medium-fine, self-mulching, grey Vertisol. The cropping sequences used were cotton followed by N- fertilized wheat (urea at 140 kg N ha^{-1} in 1993; 120 kg N ha^{-1} thereafter), unfertilized wheat, and unfertilized grain legumes (chickpea in 1993; faba bean thereafter), which were either harvested or the grain incorporated during land preparation. Soil organic C in the 0-0.6 m depth was not affected by the rotation crop, although variations occurred between times of sampling. Regression analysis indicated that there had been no net gain or loss of organic C between June 1993 and October 1998. Sowing leguminous rotation crops increased nitrate-N values. A net increase in root-zone nitrate-N reserves occurred with time (from June 1993 to October 1998) with all rotation crops. Soil compaction (measured as specific volume of oven-dried soil) was lower with wheat by October

1998. A net decrease in soil compaction occurred in the surface 0.15 m with all rotation crops between 1993 and 1998, whereas it increased in the 0.15-0.60 m depth. Cotton lint yield and quality, and gross margins ha^{-1} and gross margins ML^{-1}, were always higher where wheat was sown, with highest gross margins occurring when N fertilizer was applied. Applying N fertilizer to wheat did not significantly increase cotton lint yield and fibre quality, but increased gross margins of the cotton-wheat sequence due to higher wheat yield and protein percentage. Lint yield and fibre quality were decreased by sowing leguminous rotation crops. Management constraints such as lack of effective herbicides, insect damage, harvesting damage, and availability of suitable marketing options were greater with legumes than with wheat. Overall, wheat was a better rotation crop than grain legumes for irrigated cotton.

Zheng *et al.* (2002) stated that China is a country with shortage of fresh water resources, and the exploitation of brackish water is an important way which can mitigate the contradiction between water supply and demand in the north of China. They studied the effects of the irrigation with fresh and brackish water on soil and the growth of cotton under wheat straw mulching. The results showed that soil salt content could increase after irrigated and the growth of cotton was restrained to some extent when irrigated with brackish water. Wheat straw mulching can effectively decrease soil surface evaporation and conserve soil moisture. Moreover, wheat straw mulching can effectively restrain soil surface salification caused by irrigation with brackish water and mitigating the negative effect of irrigation with brackish water on the growth of cotton. Therefore, in dry seasons the brackish water resources with mineral concentration between 2-5 g L^{-1} can directly be used to irrigate cotton and soil salt content would not exceed the tolerance of salinity of cotton.

Under wheat straw mulching, the negative effects of irrigation with brackish water on soil and cotton can be reduced obviously.

Ghosh *et al.* (2003) conducted a series of field experiments from 1990 to 1997 in Junagadh, Gujarat, India to evaluate the effect of mulching, i.e. chopped wheat straw at 5 t ha^{-1} and black polyethylene sheet (guage, 50 micro m), on the growth and yield of summer groundnut cv. GG 2. The application of wheat straw as a mulch increased pod yield by 19.4 percent compared with the no-mulch treatment. On the other hand, black polyethylene had no beneficial effect on the pod yield of groundnut. The increase in pod yield due to wheat straw mulching was due to the increase in the availability of soil moisture and nutrients and the favourable soil temperature regime throughout the crop growth period. Black polyethylene increased germination and early crop growth due to increase in soil temperature, but it adversely affected pod and seed development, thus, it could not sustain the beneficial effect on crop yield.

Iqbal *et al.* (2003) conducted a pot experiment to evaluate the effect of mulch and irrigation level on biomass and water use efficiency of forage maize using clay and loam soils in autumn 2002. Two mulch levels, 0 (control) and 6.7 Mg ha^{-1}, and three-irrigation levels 100, 80 and 60 percent of total crop water requirement (CWR), were used. Maize plants were harvested twelve weeks after sowing, and data regarding shoot fresh weight and leaf area index were recorded. Water use efficiency was calculated. The results revealed that wheat straw mulch significantly affected the growth of maize as it decreased in fresh weight of shoot, increased in leaf area index and water use efficiency, while soil texture affected significantly the leaf area index mostly in clay soil. The maximum plant growth was noted in the case of I< sub>0</ sub> (100% CWR), followed by I< sub>2</ sub> (60% CWR) and I< sub>1</ sub>

(80% CWR) in most of the cases for all the growth parameters studied. The interactions between mulch and soil texture was found statistically significant as increase in parameters such as leaf area index, water use efficiency and decreased in biomass were observed.

Uniyal and Mishra (2003) applied five locally available mulch materials, i.e. wheat straw, green twigs, farmyard manure (FYM), piltu (dry leaves of *Pinus roxburghii*) and forest litter, to potato cv. Kufri Jyoti grown under mid-hill conditions of Uttarkhand, India, during the summer of 1998, 1999 and 2000. The mulches had significant influence on soil moisture, soil temperature, plant height, fresh shoot weight, tuber weight, number of tubers plant^{-1}, and tuber yield. Mulching with FYM was found most efficient in increasing soil moisture, soil temperature, plant height, fresh shoot weight, tuber weight, and tuber yield, followed by forest litter. Cutworm incidence in tubers was low in plots mulched with green twigs, forest litter, and wheat straw. The correlation coefficients indicated that higher tuber yield in plots mulched with FYM and forest litter was due to the ability of these mulches to conserve high soil moisture and reduce maximum soil temperature, favouring plant growth and tuber bulking, respectively.

Woldetsadik *et al.* (2003) conducted two field experiments with shallot (*Allium cepa var. ascalonicum*) on heavy clay soil to evaluate growth and yield response to mulching and nitrogen fertilization under the sub-humid tropical climate of Eastern Ethiopia during the short and main rainy seasons of 1999 with rainfalls amounting to 240 and 295 mm, respectively. The treatments included wheat straw, clear and black plastic mulches, and an unmulched control, each with nitrogen rates of 0, 75, or 150 kg ha^{-1}. Straw and black plastic mulches increased soil moisture while clear plastic reduced it considerably. Weed control was best with black and clear plastics in the short season and with black plastic or straw mulch in the main season. Both plastic mulches elevated soil temperature, especially clear plastic, which also caused most leaf tip burn. Yield increased nearly three-fold with the black plastic mulch in the short season and by one fourth in the main season compared to the bare ground. The straw and clear plastic mulches increased yield during the short season, but slightly reduced yield in the main season. The growth and yield of shallot were related to the weed control and soil moisture conservation efficiency of the mulches. Mulching did not alter the dry matter and the total soluble solids contents of the bulbs. Nitrogen fertilizer increased leaf numbers, plant height, mean bulb weight, bulb dry matter, and total soluble solids while reducing marketable bulb number, but did not significantly affect yield, leaf tip burn, or weed abundance.

Al-Hadithi (2004) conducted an experiment during the 2000 autumn and 2001 spring seasons in Iraq to estimate maize photosynthesis efficiency under deficit irrigation and soil mulching conditions. Full and deficit irrigation treatments were allocated to the main plots. The deficit irrigation treatment comprised the omission of one irrigation at establishment (S< sub>1</ sub>, 15 days), vegetation (S< sub>2</ sub>, 35 days), flowering (S< sub>3</ sub>, 40 days), and yield formation (S< sub>4</ sub>, 30 days) stages. The sub-plots were allocated for maize cultivars Synthetic 5012 (V< sub>1</ sub>) and Hybrid 2052 (V< sub>2</ sub>). The sub-sub-plots were assigned to mulch (M< sub>1</ sub>) with wheat straw and no mulch (M< sub>0</ sub>). The deficit irrigation did not affect photosynthesis efficiency in both seasons, which ranged between 1.90 and 2.15 percent in autumn and between 1.18 and 1.45 percent in spring. V< sub>2</ sub> was superior by 9.39 and 9.15%

than V< sub>1</ sub> in autumn and spring, respectively. Deficit irrigations, cultivars and mulch had no significant effects on harvest index in both seasons.

Diaz-Perez *et al.* (2004) stated that sweet onions (*Allium cepa*) are typically grown on bare soil and irrigated with high pressure systems such as sprinklers or centre pivots. A field experiment was conducted in Georgia, USA in 1999-2002 to determine the effects of irrigation system (drip or sprinkler) and mulch (bare soil, black plastic film or wheat straw) on the bolting, and bulb yield and quality of the onion. Individual bulb weight and bulb yields under drip irrigation were similar to those under sprinkler irrigation. Plants grown on bare soil had the highest total and marketable yield during the three seasons. There were no consistent differences in the bulb number or yield of plants on plastic film compared to those of plants on wheat straw. Plants on wheat straw had reduced foliar nitrogen content. Variability in yields among mulches and seasons was partly explained by changes in seasonal root zone temperature and soil water potential. Total and marketable yields and weight of individual bulbs increased with increasing root zone temperatures up to an optimum of 15.8 degrees C, followed by reductions in yields and individual bulb weight at >15.8 degrees C. Onion bolting increased with decreasing foliage nitrogen content, with plants on wheat straw having the highest bolting incidence. Bolting also increased with decreasing root zone temperatures for the season. The total and marketable yields increased with decreasing mean seasonal soil water potential down to -30 k Pa. Irrigation system and mulches had no consistent effect on the soluble solid content or pungency of onion bulbs.

Gitaitis *et al.* (2004) evaluated mulch (black plastic, wheat straw or bare ground) and irrigation (drip or overhead sprinkler) treatments for their effect on centre rot of onion (*Allium cepa*) caused by the bacterium Pantoea ananatis in an experiment conducted in Georgia, USA during 1999-2000. Irrigation type had no effect on centre rot incidence or severity during both years. In contrast, centre rot development was delayed by 7-14 days on onions grown in straw mulch or bare ground compared to those in black plastic. Straw mulch resulted in later harvest dates and was associated with reduced levels of centre rot. In contrast, black plastic increased the disease incidence and hastened the onset of the epidemic. The spatial distribution of disease incidence in both years indicated the presence of a primary disease gradient. At harvest, infected plants were segregated by treatment and by duration of infection based on disease ratings taken from the time of first symptom expression (beginning at 110-120 days after transplanting and then every 5 to 10 days until harvest). The treatments had no significant effects on the bulb yield of early and late-infected plants. However, symptom expression in terms of the number of days after planting was significantly correlated with the disease severity index. The amount of rot in bulbs from plants displaying their first symptoms only 1-2 days before harvest (late-season infection) was not significant from rot levels in control bulbs at harvest. However, four weeks after harvest, onions from plants with late-season infections exhibited significantly more rot in storage compared to the control.

Pawar *et al.* (2004) studied the effect of different mulches on soil moisture conservation and crop yield of groundnut (*Arachis hypogea*). Sugarcane trash mulch, wheat straw mulch, black plastic mulch and transparent plastic mulch were used in the study. Percent increase in soil moisture conservation over control was maximum in sugarcane trash mulch (13.6%) followed by black plastic mulch (12.3%), transparent plastic mulch (10.7%) and wheat straw mulch (7.0%). The maximum crop yield was observed in transparent plastic mulch (24.87 q ha^{-1}) followed by black plastic mulch (22.73 q ha^{-1}), sugarcane trash mulch (21.42 q ha^{-1}), wheat straw mulch (18.92 q ha^{-1}) and control (10.78 q ha^{-1}). As a result of better moisture conservation and higher crop yield the transparent plastic mulch gave the higher water use efficiency (WUE) of 37.03 kg ha^{-1} cm^{-1}, which was 83.7 percent more than that of control and proved its superiority over other mulching methods.

Swenson *et al.* (2004) stated that many growers have interests in using mulches, cover crops and conservation tillage systems in tomato production, but also have concerns about the effect of soil moisture fluctuations on fruit quality. Changes in percent soil moisture and 'Fabulous' tomato (*Lycopersicon esculentum*) fruit production in response to different mulching/tillage systems within wheat (*Triticum aestivum*) and winter rye (*Secale cereale*) cover crops were evaluated in experiments conducted during 1999 and 2000 in Carbondale, Illinois, USA. Treatments applied following the mowing of the cover crops were: (1) conventional tillage; (2) black polyethylene plastic over conventional tillage; (3) no-tillage with cover crop killed with 1.5 percent glyphosate one week prior to transplanting; (4) strip tillage with cover crop killed with a 1.5 percent glyphosate one week prior to transplanting; (5) no-tillage in which the cover crop was mowed periodically during the growing season; and (6) strip tillage with the cover crop mowed and treated similar to treatment 5. Generally, there were no differences ($P < 0.05$) between winter rye and wheat cover crops with respect to tomato quality or yields. Large amounts of cull fruit were produced in both years, regardless of moisture; however, blossom-end rot was more severe across treatments during 1999. Under drought conditions (1999 growing season), all conservation tillage treatments had higher soil moisture readings 24 h after rainfall than other treatments, but black polyethylene plastic had higher moisture levels than all other treatments under times of excessive water depletion. Under a condition of sufficient soil moisture (2000 growing season), black plastic resulted in higher soil moisture early in the season than conventional tillage systems, a response associated with greater total marketable yields. Comparisons between the various conservation tillage treatments for soil moisture and tomato yields were inconclusive, but with adequate and consistent soil moisture, conservation and conventional tillage treatments produced similar marketable yields.

Jiang *et al.* (2007) studied on water-saving effect of wheat straw mulching on rice cultivation in seasonal droughty hilly region in South China were conducted in 2004-05. The results indicated that the method which included dry seedbed nursery planting, ploughing, hand transplanting rice seedling as the way of broad and narrow row alternatively, and wheat straw mulching broad row about 10 days later, could save water by 30.04 percent, increase grain yield by 5.88 percent, water producing efficiency by 0.52 kg m^{-3} and irrigation water producing efficiency by 1.24 kg m^{-3}. The water-saving effect of wheat straw mulching in rice cultivation was related with the models of transplanting seedling and positive correlation with the amount of wheat straw and plough was water-saving, resulting in high yield and high effect more than zero-tillage.

Tunio *et al.* (2007) conducted a study to evaluate the effect of mulches and irrigation frequencies on growth and yield of sunflower in the experimental field of oilseed section, Agriculture Research Institute, Tandojam, Pakistan. The experiment was laid out in Randomised Complete Block Design (RCBD) with four replications. Plot size kept was 3x3 m. Different mulches such as control (no mulch), wheat straw, sugarcane trash and plastic sheet mulch, and different levels of irrigation such as two, three, four and five were tested. The results showed significant differences for seed germination m^{-2}, seeds $head^{-1}$, seed index (g) and seed yield kg ha^{-1} as affected by different mulches and irrigation frequencies. The results also revealed that plastic sheet mulch had maximum (2260.50) kg ha^{-1} seed yield. The yield contributing parameters such as seed index (g) and seed yield kg ha^{-1} were also significant under plastic sheet mulch treatment. The results concluded that Plastic sheet mulch produces more yield by conserving more moisture and having effective weed control. Thus, plastic mulch had better performance and could be used as good option for increasing sunflower yield. Four irrigations were found economical for better yield.

Liang *et al.* (2011) stated that mulch is considered a desirable management technology for conserving soil moisture, improving soil temperature and soil quality. This study aimed to investigate soil conditions and hot pepper (*Capsicum annuum* L.) performance in terms of leaf photosynthetic capacity, fruit yield and quality, and irrigation water use efficiency (IWUE) under such practices in greenhouse condition. A field experiment over three years was carried out with four types of mulch: without mulch (CK), wheat straw mulch (SM), plastic film mulch (FM) and combined mulch with plastic film and wheat straw (CM). Mulch could improve soil physical properties regardless of mulch materials. FM and CM treatments improved soil moistures status and soil temperature in comparison to CK control, while SM increased soil water content and decreased soil temperature. Mulch increased leaf net photosynthesis rate (PN), stomatal conductance to water vapour (gs), intercellular CO_2 concentration (Ci), and transpiration rate (E), but declined instant water use efficiency (WUEi). No significant effect of mulch application on chlorophyll fluorescence was existent for the entire growth season. Fruit yield and irrigation water use efficiency (IWUE) showed some increment under all the mulch conditions. Compared to CK, the yield was enhanced by 82.3 percent, 65.0 percent and 111.5 percent in 2008; 38.1 percent, 17.4 percent and 46.5 percent in 2009; and 14.3 percent, 6.5 percent and 19.6 percent in 2010 under SM, FM, and CM conditions, respectively. Although FM produced better fruit quality than other treatments, CM is the recommended practice for hot pepper cultivation in greenhouse condition due to working well to facilitate soil condition (moisture and temperature), plant growth, and marketable yield.

2.3 COMBINED EFFECTS OF IRRIGATION AND MULCHING ON GROWTH AND YIELD OF WHEAT

Tomar and Verma (1985) observed in a field trial in the Rabi season of 1980-81, in which winter wheat cv. Kalyansona was sown four dates from 23 October to 6 January and irrigated: before emergence; before emergence and at crown root initiation; before emergence and crown root initiation and at tillering; and before emergence and crown root initiation and at tillering at flowering and given no mulch or 5 or 10 tonnes paddy straw ha^{-1}. The number of grain $plant^{-1}$ and 1000-grain weight was the highest with increased with increasing irrigation and mulching. Further, mulching reduced fluctuation in soil temperature and delayed all growth stages of early and late sown wheat by 4-6 days. Reductions in yield was resulting from delayed sowing and consequent high irrigation and mulching.

Li *et al.* (2004) stated that it is valuable to combine irrigation of harvested rainwater with plastic film mulching technology to improve crop yield in semiarid areas. Limited irrigation after mulching is not usually practiced.

This research was to study the combination of pre-sowing irrigation and film mulch and its effect on spring wheat grain yield in semiarid Loess Plateau in China. Four treatments were employed: C - control, without pre-sowing irrigation and without mulching; I - pre-sowing irrigation of 30 mm without mulching; M - plastic film mulching without pre-sowing irrigation; and IM - 30 mm pre-sowing irrigation plus mulching. The combination of pre-sowing irrigation with film mulching increased the soil temperature in the seedling stage, reduced the water deficit, and achieved the highest shoot biomass and grain yield of the two years. It is, therefore, concluded that the combination of pre-sowing irrigation with plastic film mulching works well in increasing plant growth and yield of spring wheat and can be adopted for spring wheat production in the semiarid areas.

Huang *et al.* (2005) reported that the yield of spring wheat (*Triticum aestivum* L.), one of the major crops planted in the Loess Plateau, PR China, is mainly affected by available water. Straw mulch and irrigation are efficient ways of influencing wheat yield. It increased biomass and grain yield by 37 and 52%, respectively, in 1997, and by 20 and 26%, respectively, in 1998.The results suggest that higher crop yields in the semi-arid Loess Plateau may be achieved by using straw mulch.

Ranjita *et al.* (2007) conducted a field experiment at the Main Agricultural Research Station, Dharwad, University of Agricultural Sciences, Dharwad, India to determine the effect of irrigation schedules, mulch and antiranspirant on growth, yield and economics of wheat. Irrigations scheduled at five critical growth stages viz., crown root initiation (CRI)+tillering+late jointing+flowering+milk stage resulted in significantly higher grain yield (2545 kg ha^{-1}) over one, two and three irrigations but was on par with four irrigations scheduled at

CRI+tillering+late jointing+milk stage. Increase in yield was due to higher number of effective tillers per metre row length, number of grains per ear and 1000-grain weight. Plant height, total dry matter production per metre row length were higher in frequently irrigated treatments. Grain yield was highest (2215 kg ha^{-1}) in treatment receiving kaolin spray over control but was on par with straw mulch. Growth and yield attributing characters differed significantly due to the application of straw mulch and antitranspirant.

Singh *et al.* (2011b) stated that intensive cultivation of rice and wheat in Northwest India has resulted in air pollution from rice straw burning, soil degradation and declining groundwater resources. The retention of rice residues as a surface mulch could be beneficial for moisture conservation and yield, and for hence water productivity, in addition to reducing air pollution and loss of soil organic matter. Two field experiments were conducted in Punjab, India, to study the effects of rice straw mulch and irrigation scheduling on wheat growth, yield, water use and water productivity during 2006-2008. Mulching increased soil water content and this led to significant improvement in crop growth and yield determining attributes where water was limiting, but this only resulted in significant grain yield increase in two instances. There was no effect of irrigation treatment in the first year because of well-distributed rains. In the second year, yield decreased with decrease and delay in the number of irrigations between crown root initiation and grain filling. With soil metric potential (SMP)-based irrigation scheduling, the irrigation amount was reduced by 75 mm each year with mulch in comparison with no mulch, while maintaining grain yield. Total crop water use (ET) was not significantly affected by mulch in either year, but was significantly affected by irrigation treatment in the second year. Mulch had a positive or neutral effect on grain water productivity with respect to ET (WPET) and irrigation (WPI). Maximum WPI occurred in the treatment which received the least irrigation, but this was also the lowest yielding treatment. The current irrigation scheduling guidelines based on cumulative pan evaporation (CPE) resulted in sub-optimal irrigation (loss of yield) in one of the two years, and higher irrigation input and lower WPI of the mulched treatment in comparison with SMP-based irrigation scheduling. The results from this and other studies suggest that farmers in Punjab greatly over-irrigate wheat. Further field and modelling studies are needed to extrapolate the findings to a wider range of seasonal and site conditions, and to develop simple tools and guidelines to assist farmers to better schedule irrigation to wheat.

Zhou *et al.* (2011) stated that deficit irrigation (DI) is a water-saving irrigation strategy in which irrigation water is applied at amounts less than full crop-water requirements. The objective of this six-year field study was to determine the effect of DI in combination with straw mulch (SM) or plastic film-mulched ridge and straw-mulched furrows (RF) on grain yield and WUE in a winter wheat-summer maize rotation. Interactive effects between the water-saving management practices and N fertilizer rate were also investigated. Wheat yields in the RF+DI and SM+DI treatments were similar to the CFI treatment but slightly more than in the DI treatment. In summary, these results indicated that DI in combination with SM or RF practices increased crop yield in the winter wheat-summer maize crop rotation. Compared to CFI practices, the SM+DI and RF+DI practices reduced the amount of irrigation water applied over a six-year period by about 350 mm.

CHAPTER THREE

Materials and methods

3.1 INTRODUCTION

The experiment was conducted at the Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi, during the period from November 2008 to March 2009 and from November 2009 to March 2010.

3.2 DESCRIPTION OF THE EXPERIMENTAL SITE

3.2.1 Location

Geographically the experimental field is located at 24°17' - 24°31' N latitude and 88°28' - 88°43' E longitude at an elevation of 20 m above the sea level belonging the "High Ganges River Floodplain (AEZ-11)".

3.2.2 Soil

The soil of the experimental plot of the Department of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi, is silty loam and is slightly alkaline in reaction. The characteristics of the soil of the experimental field have been presented in the Appendix I.

3.2.3 Climate

The climate of the experimental site is tropical monsoon characterised by distinct seasons. The pre-monsoon hot season prevails in between March and June having the highest temperature. The annual average temperature was about 26.2°C (Appendix II). The maximum and minimum temperatures were recorded in April (37.44°C in 2009 and 38.32°C in 2010) and January (12.35°C in 2009 and 9.38°C in 2010), respectively.

The total annual rainfall was around 1,050 mm in both the years. During the rainy season (May to October) of both the experimental years, the study area received more than 95 percent of the total rainfall. The winter was a dry and cool season and received less than 2.0 percent of the total rainfall mostly as occasional drizzles between November and February. The monthly maximum and minimum air temperatures, and total monthly rainfall recorded during the experimental period (July 2008 to June 2010) of the study area has been presented in the Appendix II.

3.3 EXPERIMENTAL DESIGN

The experiment was laid out in a split-split-plot design assigning the irrigation treatments in the main plot, varieties in the sub-plots and different types of mulching in sub-sub-plots with three replications. Each unit plot size was 2m×2.5m i.e. $5m^2$. The distance between main plots was one metre, row to row distance was 20 cm, distance between replications was one metre. Plant spacing was five centimetres. The total number of unit plots were 96 (4×2×4×3). The border rows were not considered in the experiment because of the border effect. After emerging soft seedlings, they were thinned to obtain uniform and desirable number of plants.

3.4 EXPERIMENTAL TREATMENTS

Different levels of irrigation and mulching treatments were experimented on two wheat varieties. The treatments of the present experiment were showed in the Table 1.1.

Table 1.1: Different factors and treatment levels considered in the study

Factors	Number of treatments/ varieties	Level of treatments
Factor A: **Irrigation**	4	No irrigation (I_0) Two centimeter (2 cm) of irrigation (I_1) Four centimeter (4 cm) of irrigation (I_2) Six centimeter (6 cm) of irrigation (I_3)
Factor B: **Variety**	2	Prodip (V_1) Sufi (V_2)
Factor B: **Mulching**	4	No mulching (M_0) Water hyacinth (M_w) Rice straw (M_s) Black polythene (M_p)

(Source: Author)

3.5 PLANT MATERIALS

Two wheat varieties i.e. Prodip and Sufi were used as plant materials. Both the varieties are tolerant to diseases and pests suitable for late sowing condition (BARI, 2006). Seeds were collected from the Bangladesh Agricultural Development Corporation (BADC), Rajshahi. Germination test of seed was done in the laboratory before sowing and the percentage of germination was 95. The characteristics of the varieties used are as follows.

3.5.1 Prodip

Prodip, a high yielding variety of wheat, was released in 1998. A genetic line was produced by the hybridization of G 162 and BL 1316 in Nepal which came in Bangladesh in 1998 and after being proved as high yielding variety. It is recommended as Prodip (BARIGAM-24). The standard plant height of Prodip is 90-100 cm and the number of tillers is 4-5. The leaf of this wheat plant is spread and deep green. Days of heading are 64-66 days after sowing. The spike is generally long and the number of seeds spike^{-1} is 45-55. The grain colour is white and shiny and the grain size is bigger. The life cycle of Prodip variety is 102-110 days and yield is 3.5-5.1 t ha^{-1} by improved cultivation method. This variety is tolerant of leaf streak disease and resistant to leaf rust disease. This variety is also heat tolerant and, for this reason, the yield is higher by late sowing. The yield of this variety is typically higher than other modern varieties.

3.5.2 Sufi

Sufi, another high yielding variety of wheat, was released in 2005. It is recommended as BARIGAM-22. The standard plant height of Sufi is 90-120 cm and the number of tillers is 4-5. The leaf of this wheat plant is spread and deep green. Days of heading are 58-62 days after sowing. The spike is generally long and the number of seeds spike^{-1} is 50-55. The grain colour is white and shiny and the grain size is comparatively smaller. The life cycle of Sufi variety is 102-110 days and yield is 3.6-4.8 t ha^{-1} by improved cultivation method. This variety is tolerant of leaf streak disease and resistant to leaf rust disease. This variety is also heat tolerant and, for this reason, the yield is 10-20% higher than Kanchon by late sowing.

3.6 LAND PREPARATION

First, two ploughings were given by power tiller. After a few days the land was further ploughed and cross-ploughed by country plough and leveled by laddering and a good tilth was achieved. Weeds and stubbles were removed from the field prior to sowing seeds. The same procedure was followed for the next experimental year.

3.7 FERTILIZER APPLICATION

Nitrogen, phosphorus, potassium and sulphur fertilizers were used at 220, 180, 50 and 120 kg ha^{-1}, respectively. Urea, triple super phosphate, muriate of potash and gypsum were used as the source of N, P, K and S, respectively.

All the phosphatic, potassium and sulphur fertilizers and 2/3 of urea were applied in each plot at the final land preparation and were mixed thoroughly with soil. The rest 1/3 of urea was applied at crown root initiation stage after the first irrigation and before mulch application.

3.8 SEED TREATMENT

Before planting, seeds were treated with Vitavex-200 @ 0.25% to prevent seeds from the attack of soil borne diseases. Furadan @ 1.2 kg ha^{-1} was also used against wireworm and mole cricket.

3.9 SEED SOWING

Seeds were sown on 26 November 2008 (first year) and 23 November 2009 (second year) continuously in 20 cm apart rows. The seed rate was 120 kg ha^{-1}. After sowing, the seeds were covered with soil and slightly pressed by hands.

3.10 WEEDING AND THINNING

Two weedings were done to control weeds in the experimental field. First weeding was done with hand at 30 days after sowing which was followed by thinning and the second weeding was done at 50 days after sowing.

3.11 IRRIGATION

The irrigation treatments were applied three times to each replication. The first irrigation at 21 days after sowing (three-leaf stage), second irrigation at 51 days after sowing (booting stage) and the last one at 70 days after sowing (grain filling stage).

3.12 MULCHING

Mulch materials (rice straw = 2.5 t ha^{-1}, water hyacinth = 2 t ha^{-1} and black polythene) were applied after the first irrigation.

3.13 GENERAL OBSERVATION

General growth condition of the crop was satisfactory. No plant protection measures were taken, as the crop was not infested with insect pests and diseases.

3.14 HARVESTING

The crop started flowering more or less at the same time in different plants. Both the varieties matured at the same time and harvesting was done on 22 March 2009 (first year) and 18 March 2010 (second year). The harvested crop was bundled separately, tagged properly and taken to the threshing floor.

3.15 POST-HARVEST OPERATION

After harvesting, crop of each plot was dried separately. After that, threshing, cleaning and drying of grains were done separately plot-wise. Then the grain and straw weights of each plot were recorded. Sample plants were processed in a similar way.

3.16 DATA COLLECTION ON CROP CHARACTERS

Ten plants were randomly selected from each plot prior to harvesting for collection of data on plant characters, grain yield and its components. Data were recorded on the following characters.

a) Plant height at maturity (cm)
b) Number of total tillers plant^{-1}
c) Number of effective tillers plant^{-1}
d) Number of non-effective tillers plant^{-1}
e) Spike length (cm)
f) Extrusion length (cm)
g) Number of spikelets spike^{-1}
h) Number of fertile spikelets spike^{-1}
i) Number of sterile spikelets spike^{-1}
j) 1000-grain weight (g)
k) Grain yield (t ha^{-1})
l) Straw yield (t ha^{-1})
m) Biological yield (t ha^{-1})
n) Harvest index (%)

A brief outline of the data recording procedure has been given below.

3.16.1 Plant height at maturity (cm)

The plant height was taken from five randomly selected plants of each plot. The measurement was taken prior to harvest from the ground level to the tip of the uppermost spikelet of the spike.

3.16.2 Number of total tillers plant^{-1}

Total tillers hill^{-1} that had at least one leaf visible was counted. It included both the effective and the non-effective tillers.

3.16.3 Number of effective tillers plant^{-1}

The spike, which had seeded, was regarded as effective tillers.

3.16.4 Number of non-effective tillers plant^{-1}

The spike, which did not have seeded, was regarded as non-effective tillers.

3.16.5 Spike length (cm)

Spike length was recorded from the basal node of the rachis to the apex of each spike.

3.16.6 Extrusion length (cm)

Extrusion length was measured in centimetre (cm) between the node of the flag leaf and the base of the spike.

3.16.7 Number of spikelets spike^{-1}

Spikelets spike^{-1} was recorded and mean was calculated later on.

3.16.8 Number of fertile spikelets spike^{-1}.

Seeds contained food material inside was considered as filled seeds present on each spike were counted.

3.16.9 Number of sterile spikelets spike^{-1}.

Seeds contained no food material inside was considered as unfilled seeds present on each spike were counted.

3.16.10 1000-grain weight (g)

One hundred clear dried seeds from each plot were counted from the sample seeds and weighed by using an electric balance and then multiplied by ten to get 1000-grain weight.

3.16.11 Grain yield (t ha^{-1})

Grains obtained from each plot was sun-dried and weighed carefully. The dry weight of grains of sample was added to the respective unit plot yield to record the final grain yield (kg plot^{-1}). The grain yield was finally converted to t ha^{-1}.

3.16.12 Straw yield (t ha^{-1})

Straw obtained from each unit plot including the straw of sample plants of the respective unit plot were dried in the sun and weighed to record the final straw yield plot^{-1} and finally converted to t ha^{-1}.

3.16.13 Biological yield (t ha^{-1})

Grain yield and straw yield altogether regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Straw yield.

3.16.14 Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated with the following formula (Gardner *et al*., 1985):

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

The data on plant height, the number of total tillers plant^{-1}, the number of effective tillers plant^{-1}, spike length (cm), the number of spikelets spike^{-1}, 1000-grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) were collected from 10 randomly selected plants of each unit plot at the final harvest and the mean values were calculated for each treatment in both the year.

Grain and straw yields were determined by harvesting crops from one square meter area at the center of each plot. The weights of grain and straw yield were taken after sun-drying and cleaning. Then the values were expressed in t ha^{-1}.

3.17 DATA COLLECTION ON GROWTH CHARACTERS

3.17.1 Measurement of dry weight and leaf area

For the purpose of growth analysis, nine harvests were taken at equal intervals of 10 days. The first harvest was taken at 18 days after sowing (DAS). At each harvest, three plants were selected at random for each cultivar from each treatment. The plants were cut at the ground level and the top parts were separated into leaves, stems and panicles (when present). The plant parts were dried separately before weighing in an oven at about 85° C for 24 hours till they reached constant weights.

For determining the leaf area, three segments each of 4 cm long were taken and weighed after oven drying. Then the leaf area was calculated by using the following formula:

$$\text{Area of leaves} = \frac{\text{Area of segments} \times \text{weight of leaves}}{\text{Weight of segments}}$$

3.17.2 Growth Attributes

From the dry weight of different plant parts and leaf area data, the following growth attributes were calculated between two successive harvests by following the classical technique of growth analysis (Radford, 1967).

1. Crop growth rate (CGR) = $$\frac{W_2 - W_1}{t_2 - t_1}$$

2. Relative growth rate (RGR) = $$\frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

3. Net assimilation rate (NAR) = $$\frac{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}{(LA_2 - LA_1)(t_2 - t_1)}$$

4. Leaf area ratio (LAR) = $$\frac{(LA_2 - LA_1)(\log_e W_2 - \log_e W_1)}{(\log_e LA_2 - \log_e LA_1)(W_2 - W_1)}$$

5. Relative leaf growth rate (RLGR) = $$\frac{\log_e LA_2 - \log_e LA_1}{\mathrm{t}_2 - \mathrm{t}_1}$$

6. Leaf area index (LAI) = $\frac{\text{Total leaf area}}{\text{Ground area}}$

7. Specific leaf area (SLA) = $\frac{\text{Leaf area}}{\text{Leaf dry weight}}$

8. Leaf weight ratio (LWR) = $\frac{\text{Leaf dry weight}}{\text{Total plant dry weight}}$

Where, W_2 and W_1 are the total dry weights (g m^{-2}) and LA_2 and LA_1 are the leaf area per plant at the later (t_2) and the former (t_1) harvest time, respectively.

3.18 WATER RELATION

3.18.1 Relative leaf water content (RLWC) of wheat

Relative leaf water content was determined from the matured flag leaf. The leaves were collected at 8:00 am, 12:00 pm (noon) and 4:00 pm. Three leaves were taken from each replication of each treatment and their fresh weights were taken separately and were sunk into water kept in test tubes for four hours. After four hours they were taken off from water and after drying with blotting paper, when the cells of the leaves became fully turgid, their turgid weights were determined. Then the leaves were dried into an oven at 70°C for 48 hours and weighed. The relative leaf water content was calculated from the formula as follows (Barrs & Weatherley, 1962).

$$\text{RLWC} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.18.2 Moisture retention capacity (MRC) of wheat

Three matured flag leaves were collected from each replication and treatment and their fresh weights (FW) were taken separately. Then they were weighed at 30-minute intervals for eight times. After that they were weighed at 90-minute intervals for three times. Finally, the leaves were dried into an oven at 70°C for 48 hours and weighed. The MRC was calculated by the following formula:

$$\text{MRC} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

3.19 BIO-CHEMICAL APPROACH

3.19.1 Chlorophyll content of wheat

The chlorophyll content of the flag leaf was estimated according to Arnon (1949). Three leaf segments of each 1.5 cm^2 area were taken from the different positions of the flag leaf. Chlorophyll was extracted with 80 percent aqueous acetone using a mortar and pestle to grind the tissues. The suspension was poured into centrifuge tubes and centrifuged for three minutes. After centrifugation, the upper clean green solution was decanted from the colorless residues and made up to 10 ml with 80 percent acetone. The light transmittance of this solution was determined against 80 percent acetone as blank using a spectrophotometer at 645 nm and 663 nm. The optical density (OD) was determined by using the formula:

$$\text{OD} = 2 - \log_{10} t$$

Where, t is light transmittance of this solution in a spectrophotometer.

The chlorophyll ‘a’ and ‘b’ were determined by using the following formula given by McKinney (1941) and later used by Arnon (1949).

Chlorophyll a = 12.717 A_2 – 2.584 A_1 = mg chl. a per liter

Chlorophyll b = 22.869 A_1 – 4.670 A_2 = mg chl. a per liter

Where, A_1 and A_2 are OD at wavelengths of 645 nm and 663 nm amount of chlorophyll per unit leaf area was calculated by the following way:

$$OD = \frac{\text{mg chl. a or b per liter} \times 10}{1000 \times \text{leaf area}}$$

3.20 STATISTICAL ANALYSIS

The collected data were analysed statistically using the analysis of variance technique and the mean differences were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984) with the help of MSTAT software.

CHAPTER FOUR

Results

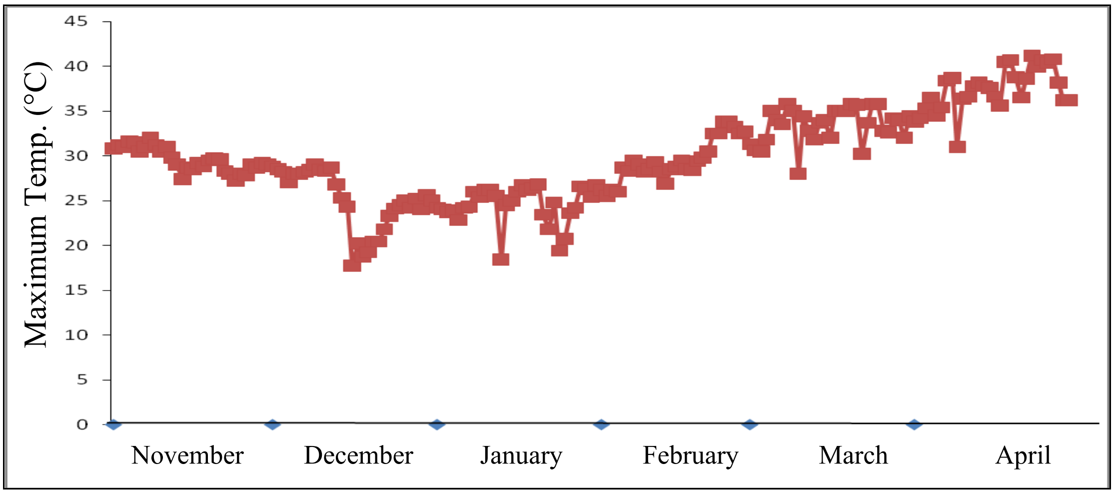
This chapter presents the results of the experiment in respect to different crop growth parameters, yield and yield contributing characters, water relations and the chlorophyll content as affected by different levels of irrigation and mulching treatments tested over two wheat varieties.

4.1 METEOROLOGICAL DATA

Monthly average air temperature (maximum and minimum) and total rainfall from sowing to the final harvest are presented in Figs. 1a, 1b and 2. Both the maximum and minimum temperatures gradually declined till January in both the years. The highest temperature was recorded in March and the lowest temperature was recorded in January during the crop period (Appendix II).

There was no rainfall up to December, very little rainfall recorded in January and February, and comparatively higher rainfall measured in March during the crop period of the first experimental year. In the second year, there was no rainfall at all during the crop period except very little in February.

A



B

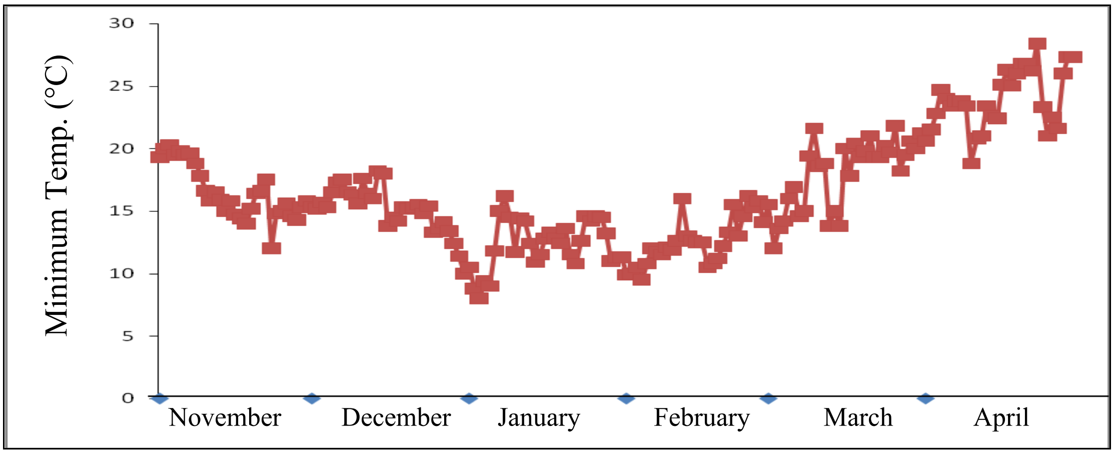
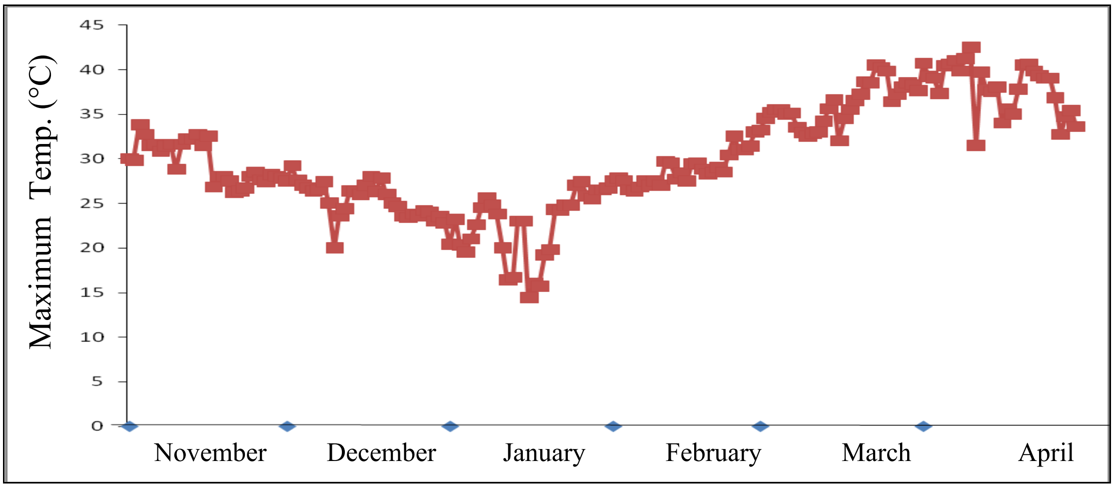


Figure 1a: Maximum and minimum temperatures during the crop-growing season of 2008-2009. A maximum temperature and B minimum temperature

A



B

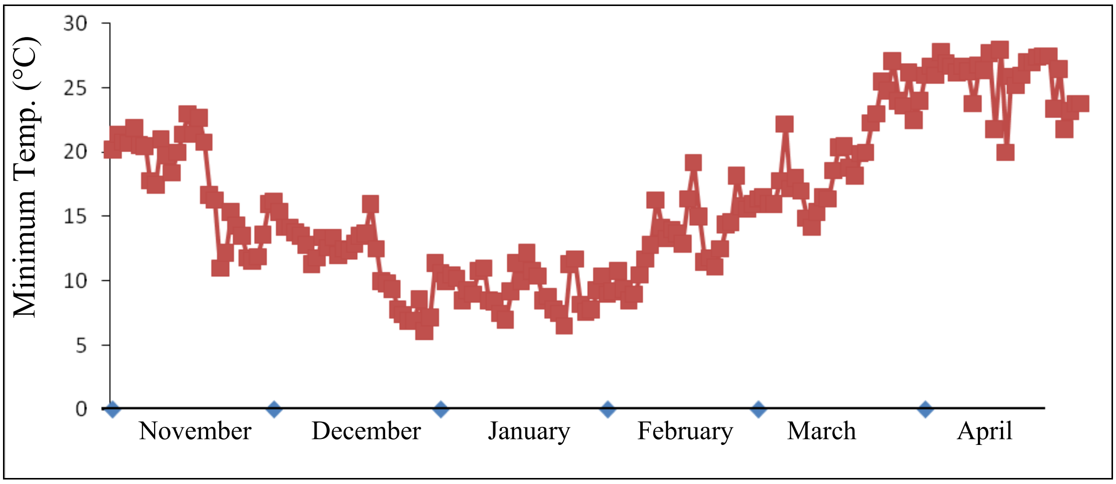
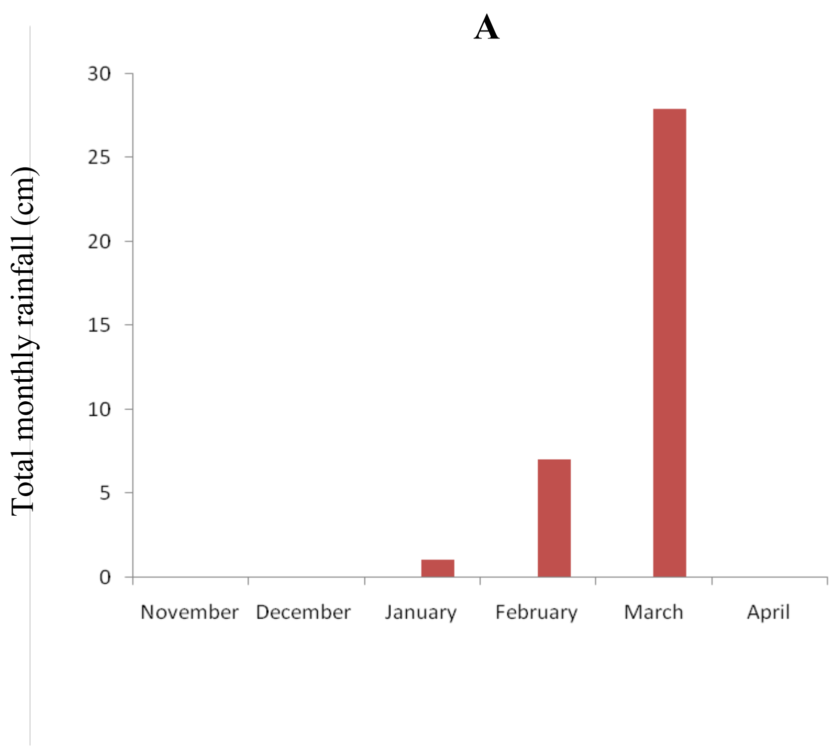


Figure 1b: Maximum and minimum temperatures during the crop-growing season of 2009-2010. A maximum temperature and B minimum temperature



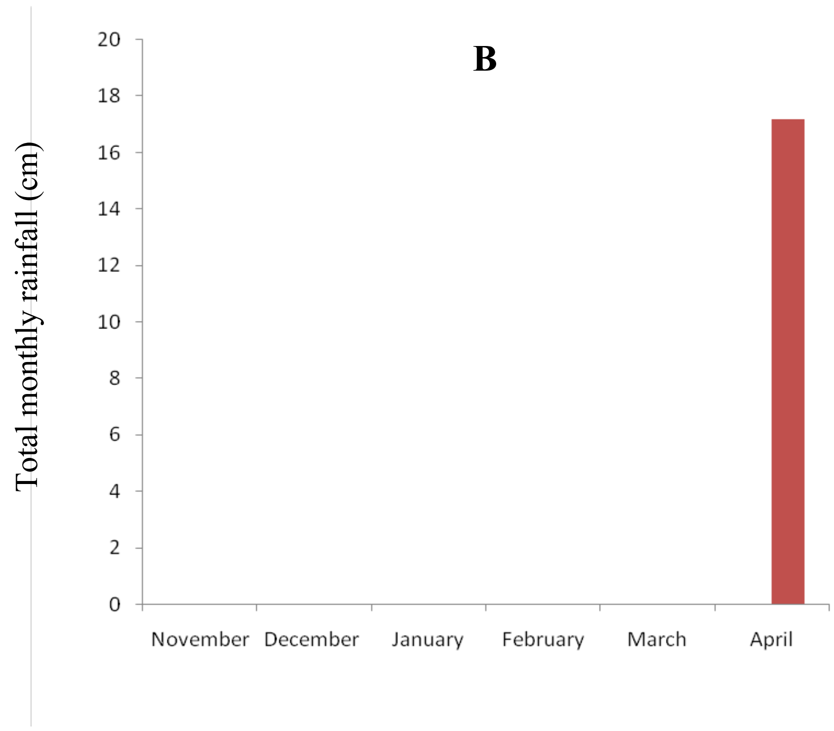


Figure 2: Monthly total rainfall during the growing season. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2 GROWTH ATTRIBUTES

4.2.1 Total dry matter (TDM)

Total dry matter (TDM) of wheat was significantly influenced by different irrigation levels (Appendices IIIa and IIIb). TDM increased steadily until 40 days after sowing (DAS) in both the years and then increased sharply with the advancement of the growth period in all the irrigation treatments and varieties (Fig. 3a). The irrigated plants had higher TDM than the rain-fed plants in both the years. I_3 treatment had the highest TDM at the last harvest. The lowest TDM was in I_0 treatment at the first harvest in both the growing seasons (Tables 2.1a and 2.1b).

Significant varietal influence on wheat was not seen in the first year but it was prominent in the second year. TDM as influenced by both the varieties at different growth stages in two growing seasons is presented in the Tables 2.1a and 2.1b. TDM increased slowly at the early harvests and increased rapidly at the later harvests in both the varieties. Both the last and first harvests had the highest and the lowest TDM respectively. Between the varieties, Prodip had higher TDM and Sufi had lower TDM.

There were no significant effect of mulching in the first year but in the second year, mulching had a significant effect on TDM. Result shows that TDM increased slowly until 40 DAS then increased sharply till harvest (Fig.3b). The highest TDM was observed in M_P treatment and the lowest TDM was observed in the control or M_0 treatment in both the years (Tables 2.1a and 2.1b).

Table 2.1a: Effect of irrigation levels, variety and mulching on TDM (g m^{-2}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)								
	20	30	40	50	60	70	80	90	100
a) Irrigation levels									
I_0	14.170b	37.309b	77.276b	137.063c	277.186c	452.370c	600.484c	744.028c	761.751
I_1	15.423ab	39.213b	81.545b	168.814b	294.858bc	479.921bc	638.229bc	790.146bc	809.355bc
I_2	16.770a	42.440b	87.996ab	181.150ab	318.940ab	519.755ab	691.005ab	855.336ab	868.554ab
I_3	17.362a	47.707a	98.172a	199.023a	353.088a	573.624a	762.287a	935.737a	941.265a
LS	**	**	**	**	**	**	**	**	**
b) Variety									
V_1	16.037	41.993	87.157	172.486	315.718	514.499	685.433	850.080a	864.656a
V_2	15.825	41.342	85.337	170.539	306.317	498.337	660.570	812.544b	825.806b
LS	NS	NS	NS	NS	NS	NS	NS	*	*
c) Mulching									
M_0	15.267	39.674	82.270	162.782	296.156	481.696	643.590	794.344	809.440
M_W	15.560	40.745	84.336	167.878	304.545	495.115	658.630	815.485	828.772
M_S	16.062	42.087	86.982	173.515	313.541	509.371	679.051	838.359	852.200
M_P	16.837	44.164	91.401	181.875	329.830	539.488	710.733	877.059	890.512
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16.13	16.42	16.70	20.50	16.72	17.24	16.26	16.20	15.98

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non Significant, CV = Coefficient of Variation

Table 2.1b: Effect of irrigation levels, variety and mulching on TDM (g m^{-2}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)								
	20	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
a) Irrigation levels									
I_0	12.37d	32.82d	67.80d	121.71d	248.65d	409.83d	547.25d	690.27d	725.56d
I_1	15.08c	40.11c	83.40c	148.73c	303.98c	496.69c	661.00c	821.16c	840.34c
I_2	17.71b	47.17b	97.92b	174.62b	355.24b	582.97b	775.24b	952.31b	952.37b
I_3	19.48a	51.93a	107.73a	263.00a	389.95a	639.50a	849.99a	1039.35a	1037.87a
LS	**	**	**	**	**	**	**	**	**
b) Variety									
V_1	16.41a	43.83a	90.74a	180.41a	331.64a	543.05a	727.33a	904.49a	924.31a
V_2	15.91b	42.18b	87.68b	173.62b	317.26b	521.45b	689.42b	847.05b	853.77b
LS	**	**	**	**	**	**	**	**	**
c) Mulching									
M_0	13.57c	36.17d	74.63d	148.53d	271.92d	442.10d	603.67d	748.67d	761.69d
M_W	15.76d	42.07c	87.49c	172.93c	319.84c	526.69c	695.03c	857.99c	872.20c
M_S	17.17a	45.93b	95.06b	187.69b	343.20b	564.04b	747.49b	923.92b	939.62b
M_P	18.13b	47.86a	99.65a	198.91a	362.87a	596.16a	787.30a	972.51a	982.64a
LS	**	**	**	**	**	**	**	**	**
CV (%)	2.33	3.23	2.96	2.26	2.26	2.36	1.90	2.02	1.69

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation, I_1 = 2 cm of irrigation, I_2 = 4 cm of irrigation, I_3 = 6 cm of irrigation
Variety : V_1 = Prodip, V_2 = Sufi
Mulching : M_0 = no mulching, M_W = water hyacinth, M_S = rice straw, M_P = black polythene

LS = Level of Significance CV = Coefficient of Variation

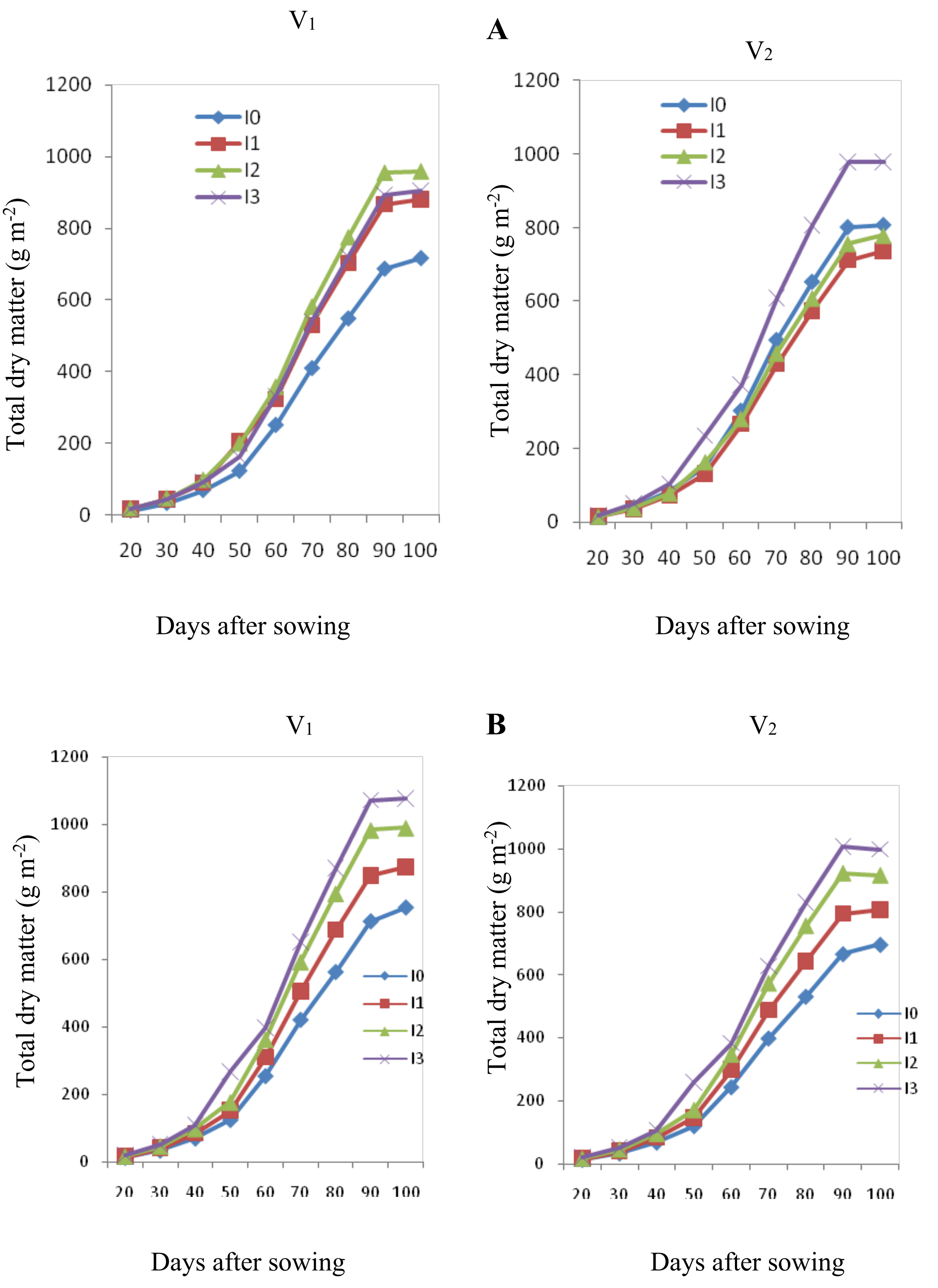


Figure 3a: Effect of irrigation levels on total dry matter (TDM) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

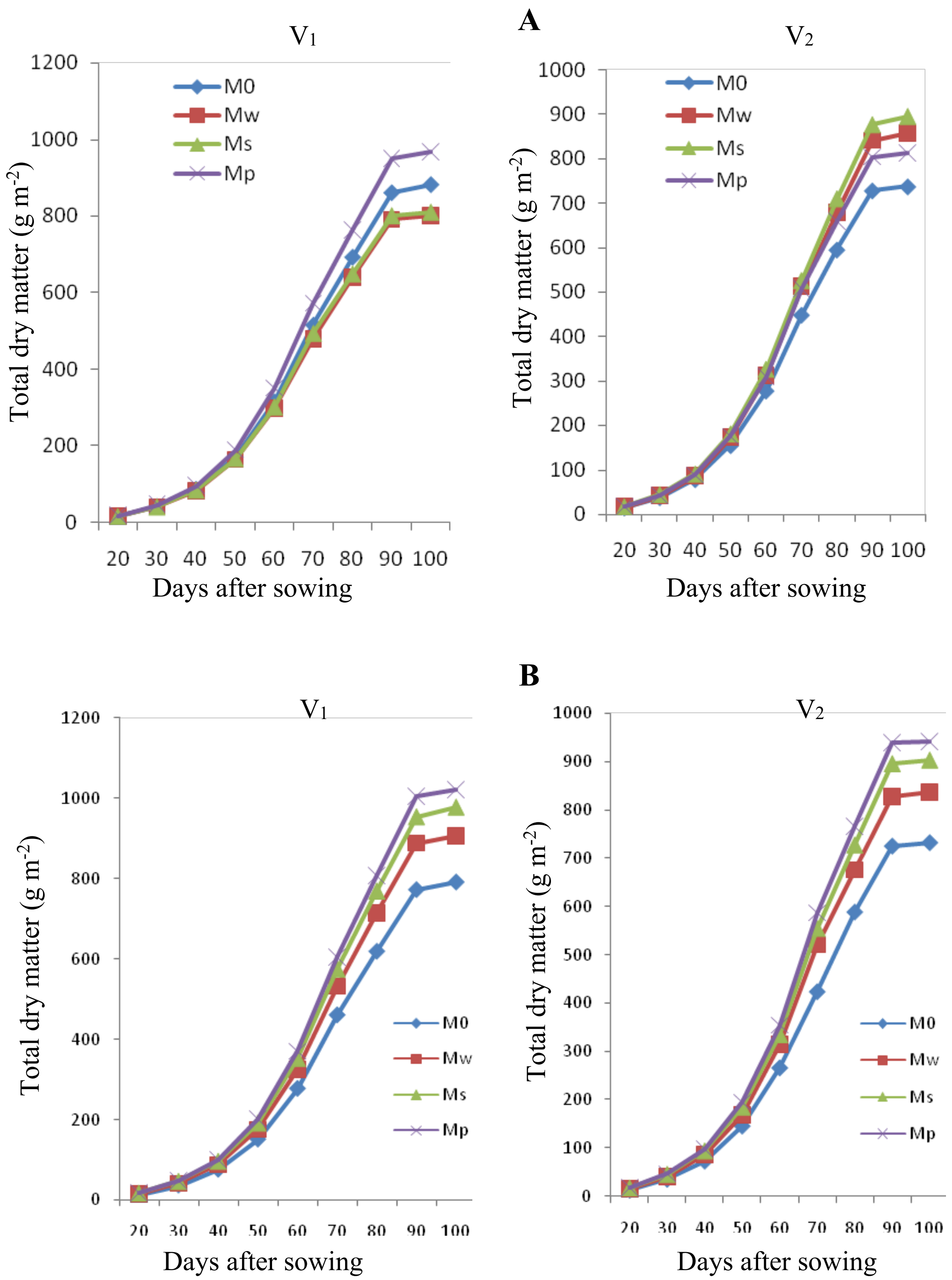


Figure 3b: Effect of mulching on total dry matter (TDM) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.2 Leaf area index (LAI)

Leaf area index was significantly influenced by irrigation in both the growing seasons (Appendices IVa and IVb). LAI of wheat varieties increased sharply until 60 to 70 DAS and then denied steadily up to the last harvest in all the irrigation treatments (Fig. 4a). Table 2.2a and 2.2b shows that the irrigated plants had higher LAI than the control. The highest LAI was observed in I_3 treatment at 70 DAS in the first year and 60 DAS in the second year. The lowest LAI was in I_0 treatment at 20 DAS in both the years.

In the first year the effect of variety on LAI was not significant with some exceptions but it was significant in the second year. Tables 2.2a and 2.2b indicate that the higher LAI was in Sufi at 60 DAS and in Prodip at 70 DAS in the first and second year respectively. The lower LAI was in Sufi at 20 DAS.

As influenced by mulching, LAI of both the varieties increased until 60 to 70 DAS sharply and then decreased with time in both the years (Fig.4b). Tables 2.2a and 2.2b show that LAI increased from the first harvest to the second last harvest (90 DAS). The highest LAI was observed in M_P treatment at 70 DAS and M_0 showed the lowest LAI at 20 DAS in both the years.

Table 2.2a: Effect of irrigation levels, variety and mulching on LAI of wheat in 2008-2009

Treatment	Days after sowing (DAS)								
	20	30	40	50	60	70	80	90	100
a) Irrigation levels									
I_0	0.283b	0.512c	1.020c	1.594c	2.595b	2.582b	2.230b	1.333b	0.803b
I_1	0.305ab	0.540bc	1.106bc	2.281b	2.745b	2.703b	2.337b	1.363b	0.826b
I_2	0.328a	0.585b	1.207ab	2.454ab	2.961ab	2.913ab	2.520b	1.445ab	0.872b
I_3	0.338a	0.654a	1.335a	2.714a	3.317a	3.343a	2.886a	1.563a	0.975a
LS	**	**	**	**	**	**	**	**	*
b) Variety									
V_1	0.314	0.570	1.158	2.225b	2.898	2.880b	2.478b	1.423	0.878a
V_2	0.313	0.575	1.177	2.296a	2.911	2.890a	2.508a	1.429	0.861b
LS	NS	NS	NS	*	NS	*	**	NS	*
c) Mulching									
M_0	0.301	0.548	1.116	2.134	2.797	2.719	2.381	1.362	0.827
M_W	0.305	0.558	1.137	2.208	2.782	2.810	2.426	1.391	0.851
M_S	0.316	0.579	1.174	2.294	2.937	2.882	2.516	1.437	0.875
M_P	0.332	0.607	1.242	2.406	3.103	3.129	2.649	1.514	0.923
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16.52	15.49	15.93	24.67	17.72	20.94	15.52	14.42	15.25

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.2b: Effect of irrigation levels, variety and mulching on LAI of wheat in 2009-2010

Treatment	Days after sowing (DAS)								
	20	30	40	50	60	70	80	90	100
a) Irrigation levels									
I_0	0.241d	0.440d	0.884d	1.398d	2.214d	2.179d	1.883d	1.330d	0.721d
I_1	0.295c	0.536c	1.084c	1.701c	2.720c	2.669c	2.329c	1.353c	0.855c
I_2	0.345b	0.630b	1.289b	1.995b	3.206b	3.151b	2.758b	1.483b	0.934b
I_3	0.380a	0.691a	1.415a	3.937a	3.515a	3.470a	3.025a	1.553a	0.983a
LS	**	**	**	**	**	**	**	**	**
b) Variety									
V_1	0.319a	0.582	1.179a	2.281a	2.953a	2.969a	2.515a	1.445a	0.913a
V_2	0.312b	0.567	1.157b	2.235b	2.875b	2.765b	2.482b	1.414b	0.833b
LS	**	**	**	**	**	**	**	**	**
c) Mulching									
M_0	0.264d	0.484d	0.974d	1.907d	2.383c	2.204d	2.104c	1.193d	0.736d
M_W	0.307c	0.562c	1.148c	2.214c	2.810b	2.885c	2.443b	1.402c	0.861c
M_S	0.335bb	0.612b	1.244b	2.374b	3.273a	3.098b	2.672a	1.528b	0.921b
M_P	0.356a	0.638a	1.305a	2.536a	3.189a	3.282a	2.776a	1.596a	0.976a
LS	**	**	**	**	**	**	**	**	**
CV (%)	6.01	5.46	4.17	4.39	4.06	5.59	6.06	5.05	4.93

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance CV = Coefficient of Variation

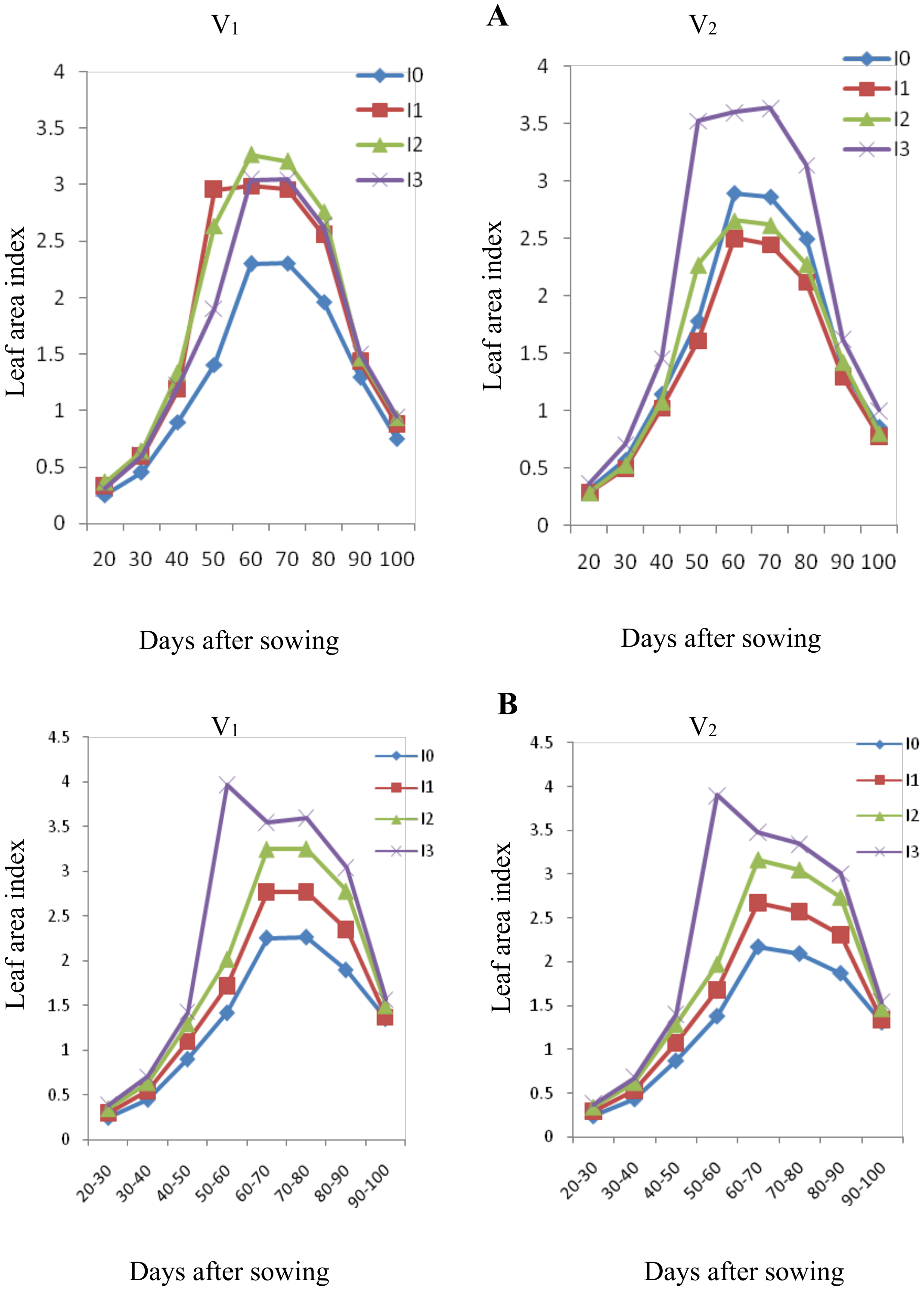


Figure 4a: Effect of irrigation levels on leaf area index (LAI) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

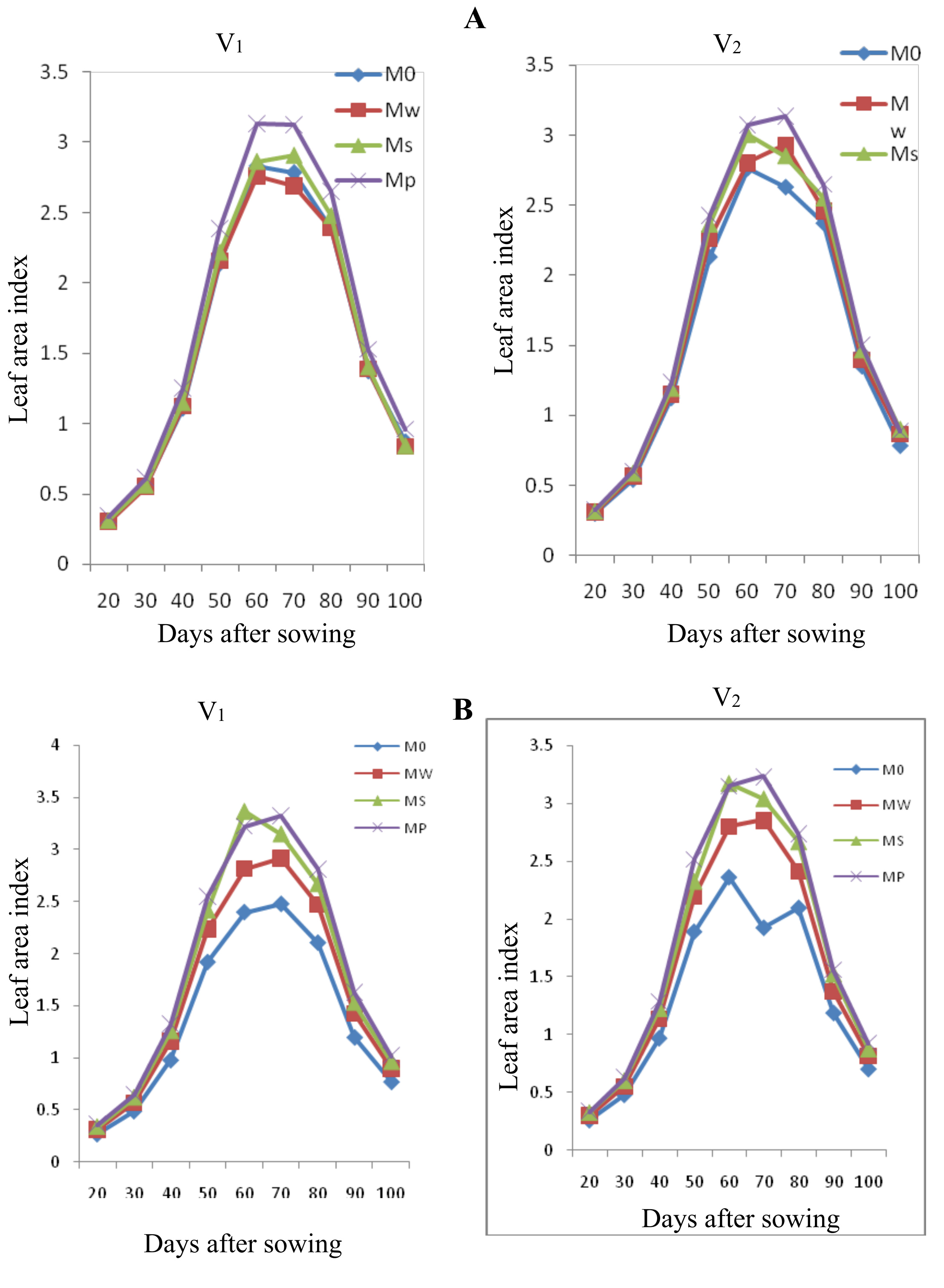


Figure 4b: Effect of mulching on leaf area index (LAI) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.3 Crop growth rate (CGR)

Crop growth rate (CGR) of wheat was significantly affected by irrigation levels. From the Fig. 5a, it was observed that CGR of both the wheat varieties increased rapidly at the early growth stages, reached the highest peak at 60-70 DAS in both the growing seasons and finally declined within very short time at the later stages of the growth in both the varieties. The irrigated plants had higher CGR from the first harvest to the second last harvest (Table 2.3a and 2.3b). I_3 treatment had the highest CGR at also 60-70 DAS and it also showed the lowest CGR at last harvest in both the years.

CGR influenced by variety increased up to the 60-70 DAS and declined very slowly at later growth stages (Tables 2.3a and 2.3b). Prodip had higher CGR at all the growth stages. The highest CGR was observed in Prodip at 60-70 DAS and the lowest CGR in Sufi at the last harvest.

Mulching had significant effect on CGR of wheat only in the second year (Appendices Va and Vb). From the Fig. 5b, it is seen that CGR influenced by mulching increased rapidly in the early growth stages, reached the peak at 60-70 DAS and then declined in both the varieties in both the years. M_P treatment had the highest CGR at the 60-70 DAS followed by M_S, and M_W had the lowest CGR was at the final harvest (Tables 2.3a and 2.3b).

Table 2.3a: Effect of irrigation levels, variety and mulching on CGR (g m^{-2} d^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
a) Irrigation levels								
I_0	2.314b	3.997b	5.979b	14.012ab	17.518b	14.811c	14.354c	1.996a
I_1	2.379b	4.233b	8.727a	12.604b	18.507b	15.831bc	15.192bc	1.921a
I_2	2.567b	4.555ab	9.316a	13.779ab	20.081ab	17.125ab	16.433ab	1.322ab
I_3	3.035a	5.047a	10.085a	15.407a	22.054a	18.866a	17.345a	0.553b
LS	**	**	**	**	**	**	**	*
b) Variety								
V_1	2.596	4.516	8.533	14.323a	19.878	17.093a	16.465a	1.570
V_2	2.552	4.400	8.520	13.578b	19.202	16.223b	15.197b	1.326
LS	NS	NS	NS	*	NS	*	**	NS
c) Mulching								
M_0	2.441	4.260	8.052	13.337	18.554	16.189	15.075	1.733
M_w	2.519	4.359	8.354	13.667	19.057	16.351	15.686	1.329
M_s	2.603	4.490	8.653	14.003	19.583	16.968	15.931	1.384
M_p	2.733	4.724	9.047	14.795	20.966	17.125	16.633	1.345
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	16.79	16.98	26.45	17.30	18.28	14.86	16.49	14.86

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels	:	I_0 = no irrigation	I_1 = 2 cm of irrigation	I_2 = 4 cm of irrigation	I_3 = 6 cm of irrigation
Variety	:	V_1 = Prodip	V_2 = Sufi		
Mulching	:	M_0 = no mulching	M_W = water hyacinth	M_S = rice straw	M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.3b: Effect of irrigation levels, variety and mulching on CGR (g m^{-2} d^{-1}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20-30	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
a) Irrigation levels								
I_0	2.05d	3.50d	5.39d	12.69c	16.12d	13.74d	14.30d	3.75a
I_1	2.50c	4.33c	6.53c	15.53b	19.27c	16.43c	16.02c	1.92b
I_2	2.95b	5.07b	7.67b	18.06a	22.77b	19.23b	17.71b	0.01c
I_3	3.25a	5.58a	15.53a	12.70d	24.96a	21.05a	18.94a	-0.15d
LS	**	**	**	**	**	**	**	**
b) Variety								
V_1	2.74a	4.69	8.97a	15.12a	21.14a	18.43a	17.72a	2.09a
V_2	2.63b	4.55	8.59b	14.37b	20.42b	16.80b	15.76b	0.67b
LS	**	NS	.**	**	*	**	**	*
c) Mulching								
M_0	2.26d	3.85d	7.39d	12.34d	17.02d	16.16d	14.50d	1.53
M_w	2.63c	4.54c	8.54c	14.69c	20.69c	16.83c	16.30c	1.42
M_s	2.88b	4.91b	9.26b	15.55b	22.09b	18.35b	17.64b	1.57
M_p	2.97a	5.18a	9.93a	16.40a	23.33a	19.11a	18.52a	1.01
LS	**	**	**	**	**	**	**	NS
CV (%)	5.58	7.16	6.19	4.31	6.46	9.26	13.18	15.20

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene
LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

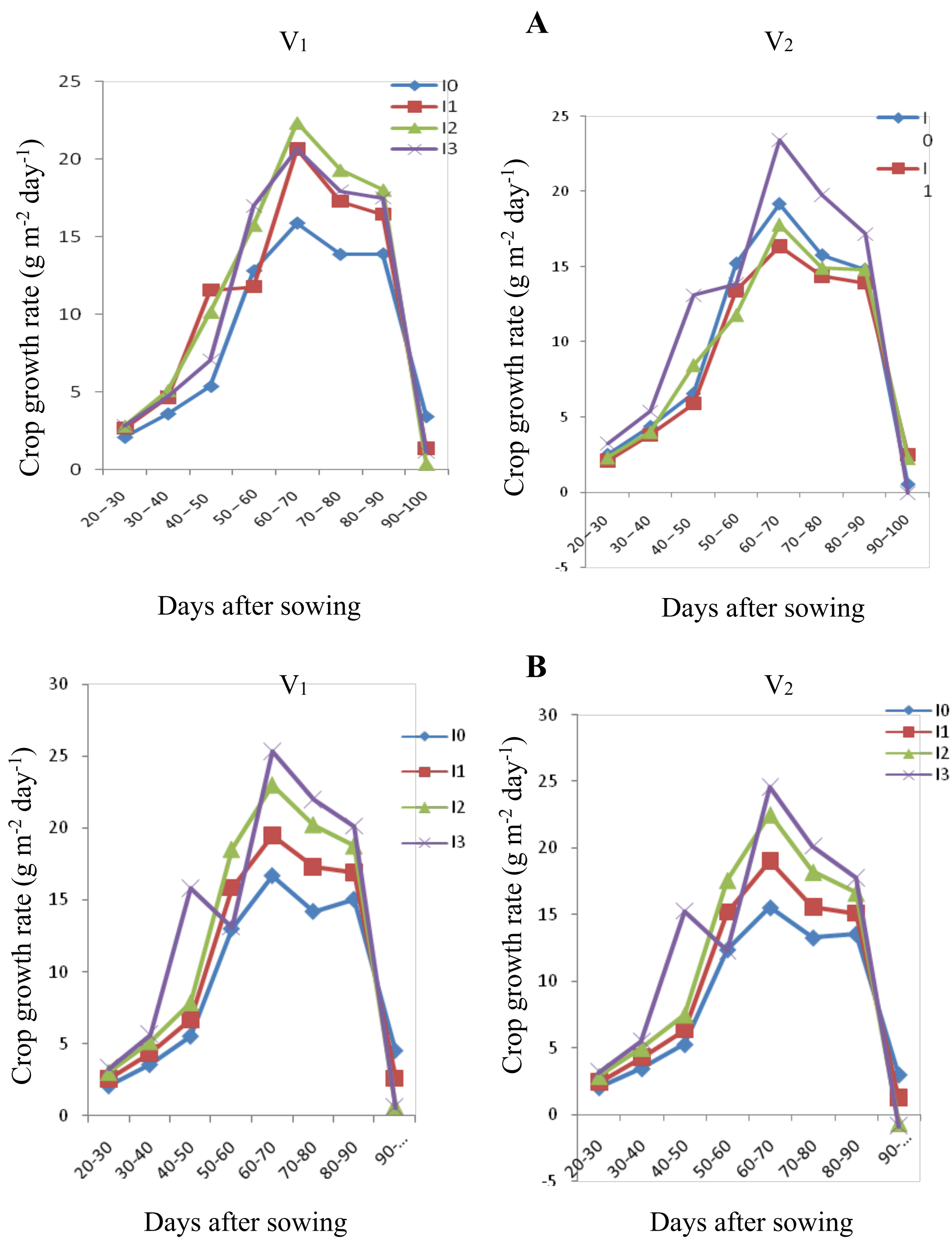


Figure 5a: Effect of irrigation levels on crop growth rate (CGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

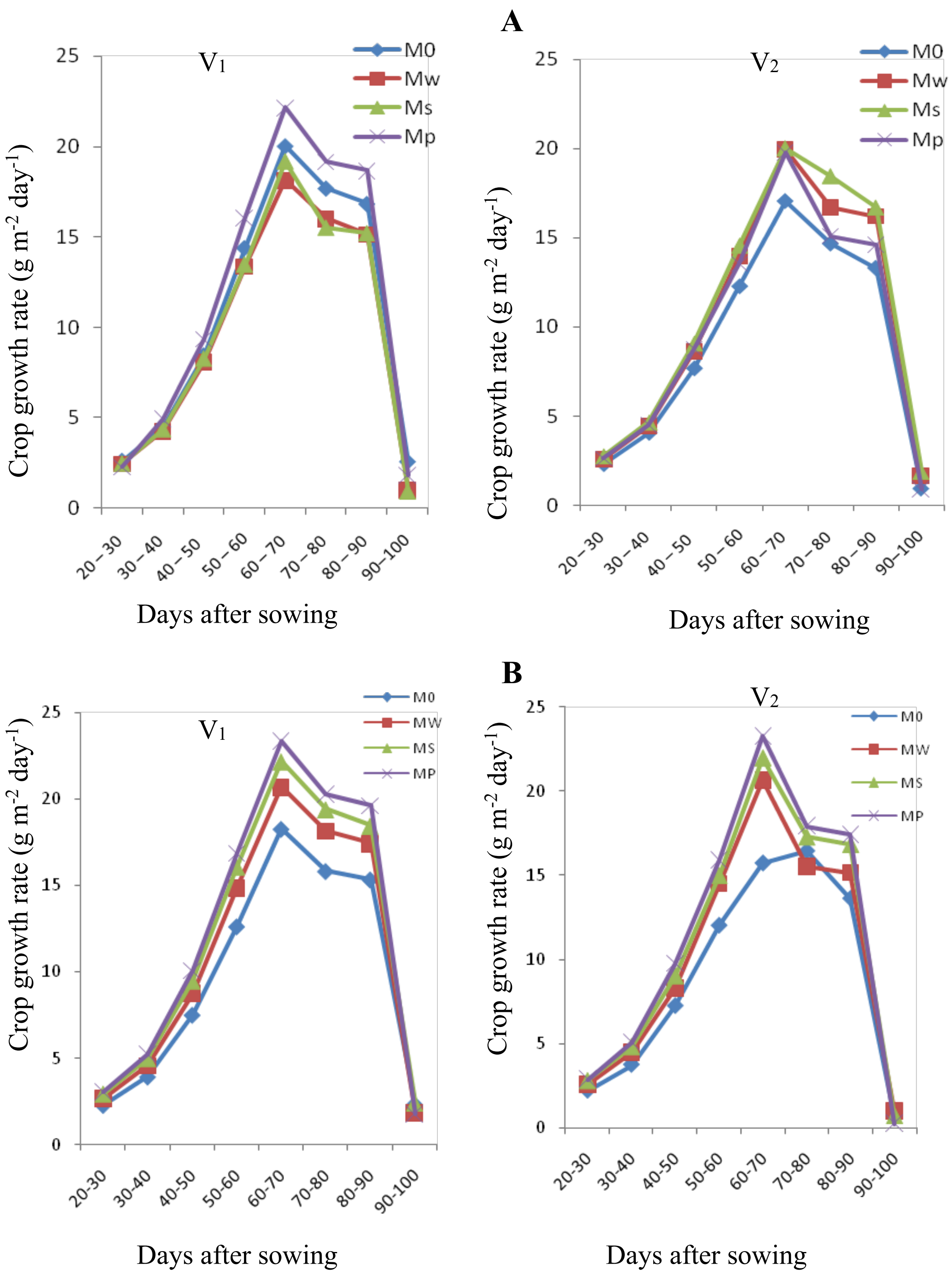


Figure 5b: Effect of mulching on crop growth rate (CGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.4 Relative growth rate (RGR)

Relative growth rate (RGR) of the two wheat varieties at different growth stages influenced by different levels of irrigations indicated that RGR declined throughout the whole growing season in every experimental year (Fig.6a). Both the highest and the lowest RGR were observed in I_0 and I_3 treatment at 20-30 DAS and at 90-100 DAS, respectively (Tables 2.4a and 2.4b).

Variety had no significant effect on RGR of the two wheat varieties with some exceptions. Both the varieties showed the highest RGR at 20-30 DAS whereas the lowest RGR was observed at 90-100 DAS in both the varieties and both the years.

There was no significant influence of mulching on RGR of wheat except 70-80 DAS in the second year. Result shows that RGR declined throughout the growing stages in both the experimental growing seasons as influenced by mulching (Fig. 6b). M_P treatment showed the highest RGR at 20-30 DAS in the first year which was similar with M_W and M_S treatments but in the second year M_0, M_W and M_S showed the highest result. All the mulching treatments showed the lowest RGR at last harvest (Table: 2.4a and 2.4b)

Table 2.4a: Effect of irrigation levels, variety and mulching on RGR (g g^{-1} d^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20-30	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
a) Irrigation levels								
I_0	0.097ab	0.073	0.057b	0.070a	0.049	0.029	0.022	0.003
I_1	0.093b	0.073	0.069a	0.059b	0.049	0.029	0.022	0.003
I_2	0.094ab	0.073	0.069a	0.059b	0.049	0.029	0.021	0.002
I_3	0.101a	0.072	0.068a	0.060b	0.048	0.029	0.020	0.001
LS	**	NS	**	**	NS	NS	NS	NS
b) Variety								
V_1	0.096	0.073	0.066	0.063	0.049	0.029	0.022	0.002
V_2	0.096	0.072	0.066	0.062	0.049	0.028	0.021	0.002
LS	NS	NS	NS	NS	NS	NS	NS	NS
c) Mulching								
M_0	0.095	0.073	0.066	0.062	0.049	0.029	0.021	0.002
M_w	0.096	0.073	0.066	0.062	0.048	0.029	0.021	0.002
M_s	0.096	0.072	0.066	0.062	0.048	0.029	0.021	0.002
M_p	0.096	0.073	0.066	0.062	0.049	0.027	0.021	0.002
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.56	1.33	9.84	11.04	3.57	8.39	4.57	14.65

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.4b: Effect of irrigation levels, variety and mulching on RGR (g g^{-1} d^{-1}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
a) Irrigation levels								
I_0	0.098	0.073	0.058b	0.071a	0.050	0.029	0.023a	0.005a
I_1	0.098	0.073	0.058b	0.071a	0.049	0.029	0.022a	0.002b
I_2	0.098	0.073	0.058b	0.071a	0.049	0.029	0.021a	-0.000c
I_3	0.098	0.073	0.089a	0.039b	0.049	0.029	0.020b	-0.000c
LS	NS	NS	**	**	NS	NS	**	**
b) Variety								
V_1	0.098	0.073	0.066	0.064	0.049	0.029a	0.022a	0.002a
V_2	0.098	0.073	0.066	0.063	0.049	0.028b	0.021b	0.001b
LS	NS	NS	NS	NS	NS	**	**	*
c) Mulching								
M_0	0.098	0.072	0.066	0.063	0.049	0.031a	0.022	0.002
M_w	0.098	0.073	0.065	0.064	0.050	0.028b	0.021	0.002
M_s	0.098	0.073	0.065	0.063	0.050	0.028b	0.021	0.002
M_p	0.097	0.073	0.066	0.063	0.050	0.028b	0.021	0.001
LS	NS	NS	NS	NS	NS	**	NS	NS
CV (%)	4.03	6.13	5.51	3.33	5.82	8.93	12.60	14.02

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

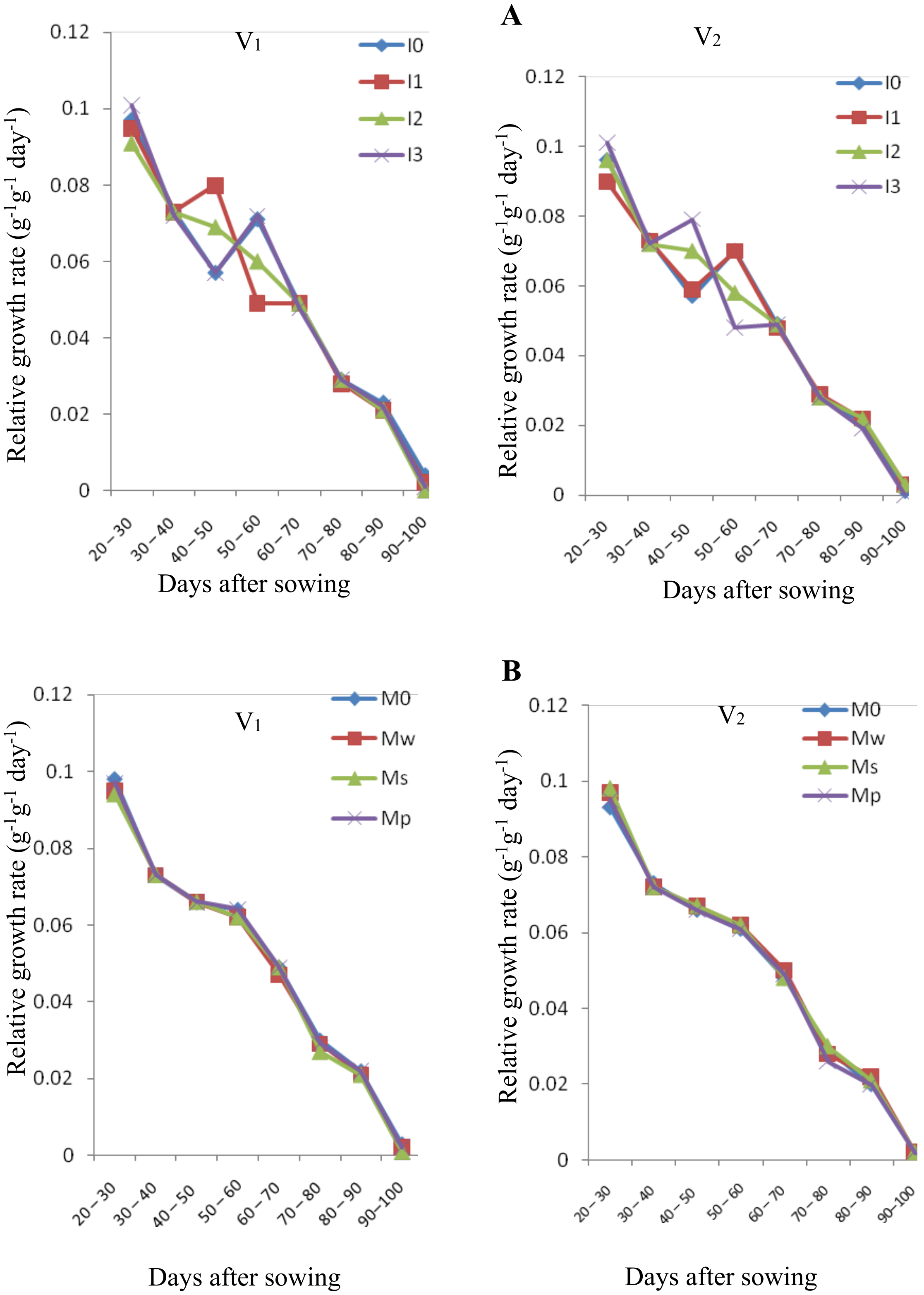


Figure 6a: Effect of irrigation levels on relative growth rate (RGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

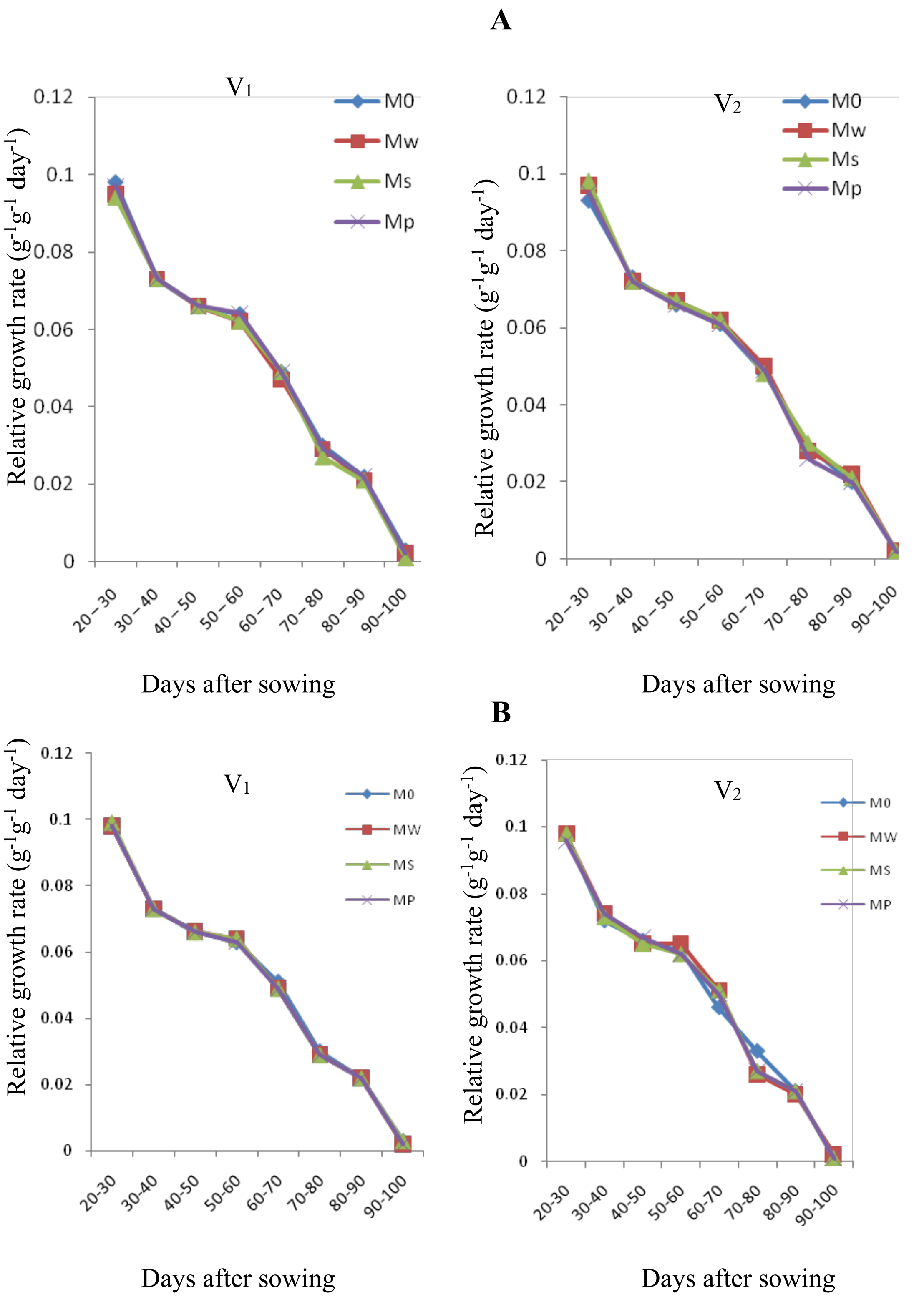


Figure 6b: Effect of mulching on relative growth rate (RGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.5 Net assimilation rate (NAR)

Influence of irrigation on net assimilation rate (NAR) of wheat was more significant in first year than in the second year (Appendices VIIa and VIIb). From the Fig. 7a and 7b, we can assume that NAR had a fluctuating tendency throughout the growing season in every year. Tables 2.5a and 2.5b illustrates that NAR fluctuated with different irrigation levels in different growth stages. The highest NAR was observed in I_2 and I_0 treatments at 60-70 DAS in the first and second year respectively. The lowest NAR was seen in I_3 treatment at the last harvest.

With some exceptions variety had a significant effect on net assimilation rate (App). NAR influenced by the two wheat varieties also fluctuated at different growth stages (Tables 2.5a and 2.5b). The highest NAR was seen both in Prodip and Sufi at 60-70 DAS in the first and second year respectively.

Mulching had no significant effect on NAR with some exceptions in second year. Fig. 7b highlights that NAR was influenced by different mulching treatments and started to decline from a higher range with a fluctuating tendency. The highest NAR was observed in M_W at 60-70 and M_0 at 70-80 DAS and M_P at the last harvest showed the lowest NAR (Tables 2.5a and 2.5b).

Table 2.5a: Effect of irrigation levels, variety and mulching on NAR (g cm^{-2} d^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
a) Irrigation levels								
I_0	0.598b	0.541a	0.465b	0.684a	0.677	0.624	0.825	0.179a
I_1	0.575b	0.534ab	0.517a	0.557b	0.681	0.638	0.846	0.193a
I_2	0.583b	0.529b	0.513a	0.557b	0.687	0.638	0.853	0.128a
I_3	0.632a	0.529b	0.503a	0.558b	0.663	0.614	0.808	0.047b
LS	**	**	**	**	NS	NS	NS	**
b) Variety								
V_1	0.604a	0.544a	0.507a	0.605a	0.690a	0.644a	0.868a	0.142
V_2	0.590b	0.523b	0.492b	0.573b	0.664b	0.613b	0.798b	0.131
LS	*	*	*	*	*	**	*	NS
c) Mulching								
M_0	0.592	0.534	0.498	0.587	0.674	0.644	0.830	0.153
M_w	0.600	0.535	0.502	0.595	0.682	0.635	0.846	0.132
M_s	0.598	0.533	0.500	0.585	0.676	0.638	0.832	0.134
M_p	0.598	0.533	0.497	0.587	0.676	0.596	0.824	0.127
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.73	4.00	7.48	14.19	6.60	13.38	9.89	16.05

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.5b: Effect of irrigation levels, variety and mulching on NAR (g cm^{-2} d^{-1}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20-30	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
a) Irrigation levels								
I_0	0.618	0.550	0.481b	0.717a	0.737	0.686	0.900	0.359a
I_1	0.621	0.557	0.478b	0.716a	0.719	0.665	0.891	0.177b
I_2	0.623	0.551	0.475b	0.709a	0.719	0.659	0.864	0.000c
I_3	0.625	0.553	0.630a	0.342b	0.717	0.657	0.861	-0.011c
LS	NS	NS	**	**	NS	NS	NS	**
b) Variety								
V_1	0.627a	0.555	0.522a	0.628a	0.719	0.677a	0.923a	0.186a
V_2	0.616b	0.550	0.510b	0.614b	0.727	0.657b	0.835b	0.077b
LS	**	NS	*	*	NS	**	**	*
c) Mulching								
M_0	0.623	0.549	0.518	0.626a	0.745a	0.758a	0.906	0.150
M_w	0.623	0.554	0.511	0.636a	0.730a	0.636b	0.872	0.141
M_s	0.626	0.552	0.514	0.601b	0.695b	0.639b	0.866	0.143
M_p	0.615	0.556	0.521	0.622ab	0.722a	0.634b	0.871	0.091
LS	NS	NS	NS	**	**	**	NS	NS
CV (%)	6.07	7.07	5.71	4.90	6.58	10.09	12.22	15.58

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

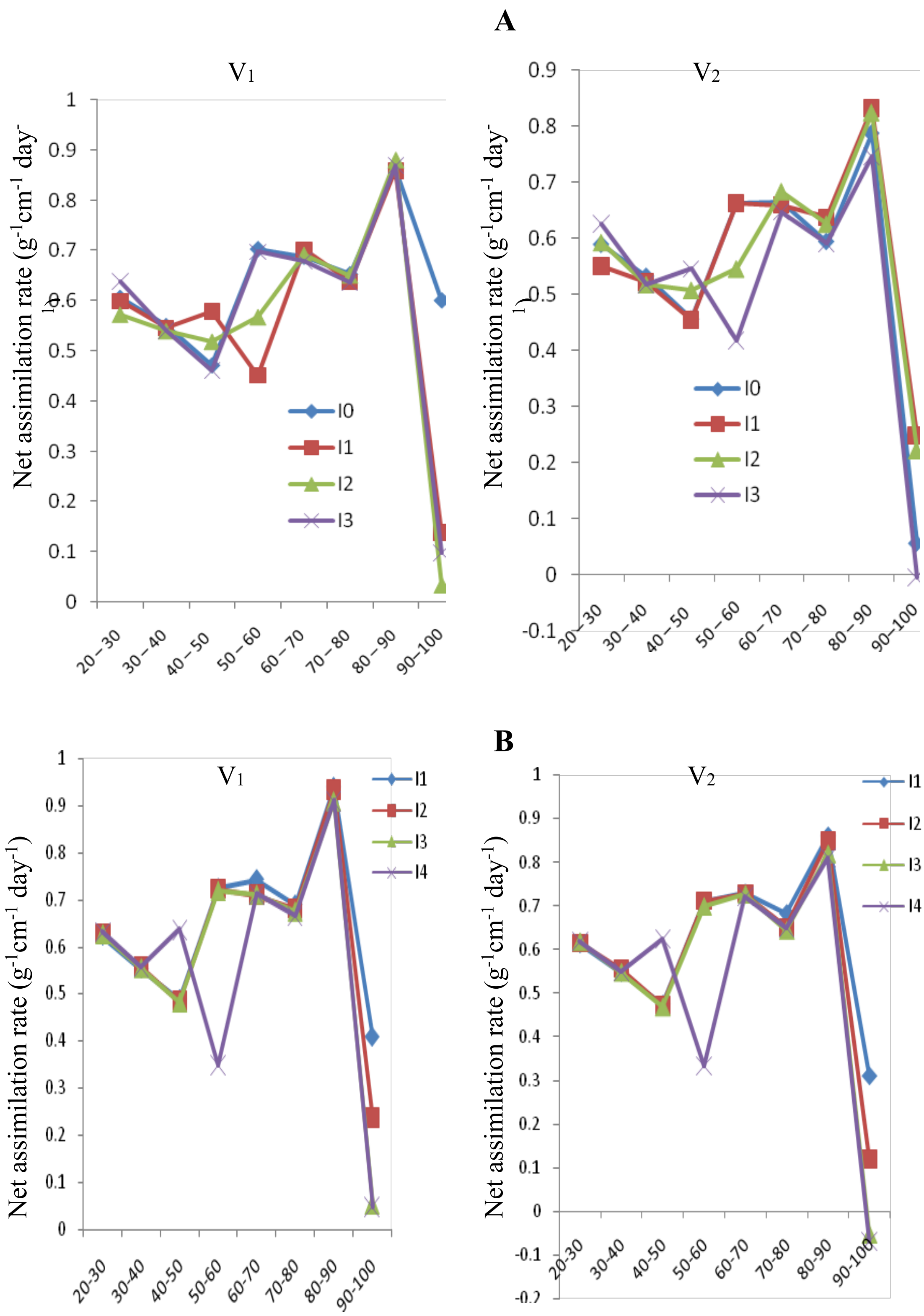


Figure 7a: Effect of irrigation levels on net assimilation rate (NAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

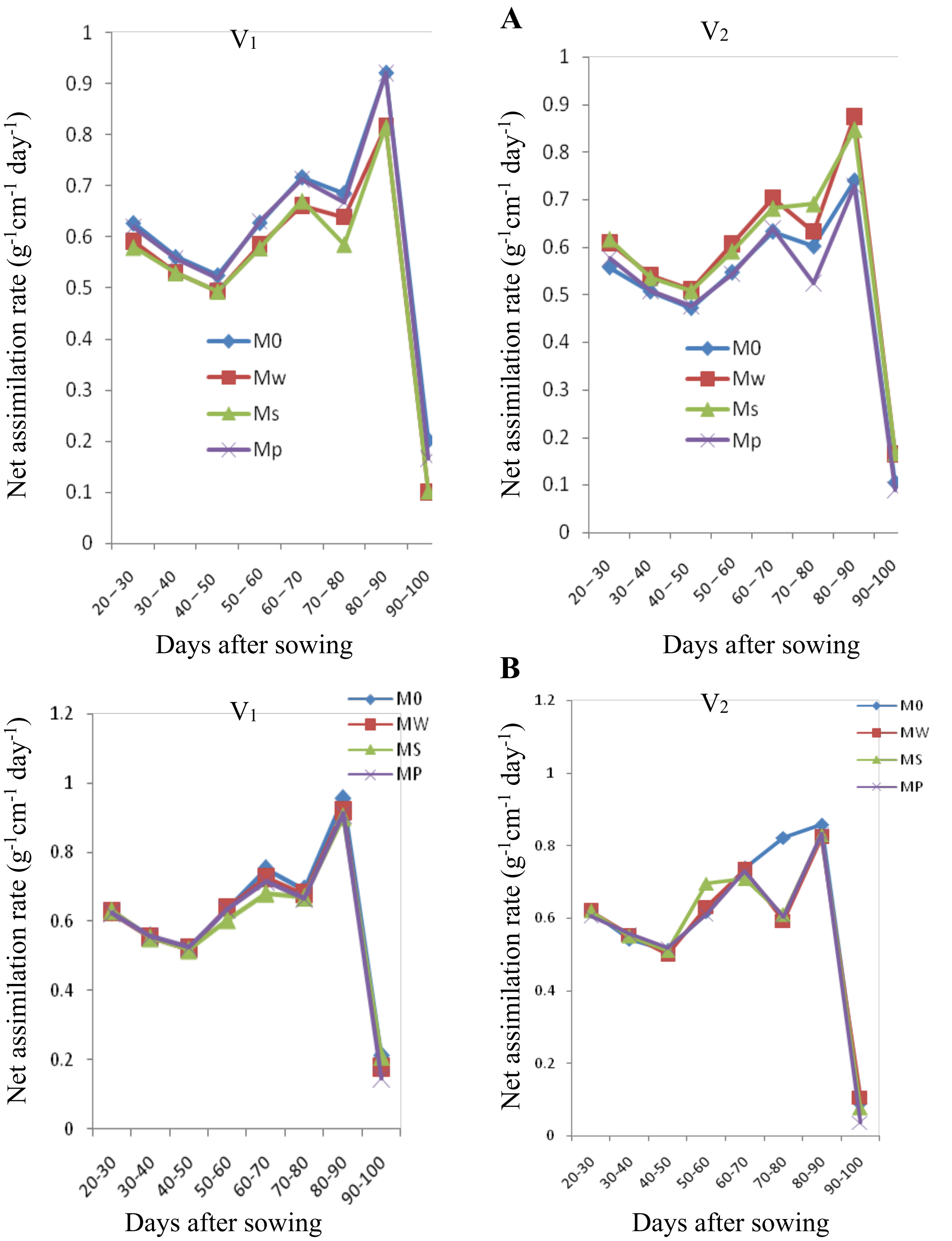


Figure 7b: Effect of mulching on net assimilation rate (NAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.6 Leaf area ratio (LAR)

No significant influence of irrigation on leaf area ratio (LAR) was found in both the years with some exceptions (Appendices VIIIa and VIIIb). Results reveals that LAR influenced by different irrigation levels started from a higher peak declined throughout the whole growing season with the advancement of time in both the varieties and both the years (Fig. 8a). Tables 2.6a and 2.6b show that irrigation treatments had fluctuating characters throughout both the growing seasons. The highest LAR was observed in I_0 treatment at 20 DAS and the lowest LAR was observed in I_2 treatment at the final harvest in both the years.

Tables 2.6a and 2.6b show that LAR of both the varieties started from the highest peak and gradually declined with the advancement of the entire growth stage. With few exceptions Sufi showed higher LAR over Prodip in both the growing seasons. The highest LAR was found in Sufi at 20 DAS and the lowest LAR was observed in Prodip at the final harvest.

Mulching-influenced LAR declined throughout the entire growing season in both the years and both the varieties (Fig. 8b). The highest LAR was M_0 treatment at 20 DAS whereas the lowest LAR was observed in M_W treatment in the first year and M_0 in the second year at the final harvest (Tables 2.6a and 2.6b).

Table 2.6a: Effect of irrigation levels, variety and mulching on LAR (cm^2 g^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
a) Irrigation levels								
I_0	161.896	134.679	123.574b	103.463b	72.403	45.992	26.299	14.052a
I_1	161.558	137.197	133.245a	109.156a	71.630	45.245	25.620	13.572ab
I_2	160.797	137.762	134.114a	109.225a	71.350	45.108	25.381	13.349b
I_3	160.013	136.740	133.993a	110.275a	73.203	46.866	25.641	13.363b
LS	NS	NS	**	**	NS	NS	NS	**
b) Variety								
V_1	159.645b	134.443b	128.799b	106.110b	71.013b	44.931b	25.127b	13.334b
V_2	162.488a	138.746a	133.664a	109.949a	73.280a	46.674a	26.343a	13.834a
LS	**	*	*	*	**	**	**	*
c) Mulching								
M_0	161.360	136.949	131.220	108.407	62.163	45.566	25.731	13.553
M_w	160.718	136.187	130.859	106.824	71.256	45.557	25.595	13.547
M_s	161.048	136.425	131.312	108.326	71.935	45.611	25.743	13.568
M_p	161.139	136.817	131.534	108.561	73.233	46.477	25.873	13.668
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.67	3.57	4.78	5.64	6.13	6.21	7.00	6.19

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.6b: Effect of irrigation levels, variety and mulching on LAR ($cm^2\ g^{-1}$) of wheat in 2009-2010

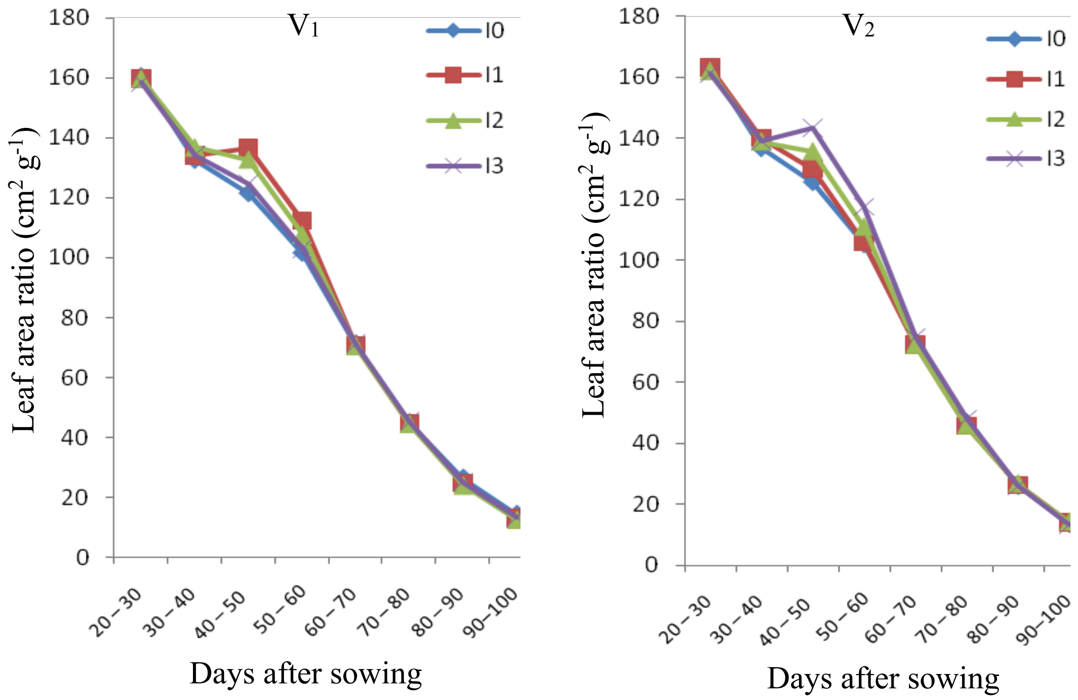
Treatment	Days after sowing (DAS)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
a) Irrigation levels								
I_0	157.82	131.96	121.64b	99.77b	67.85	42.53	25.81a	14.04a
I_1	157.60	131.54	121.25b	99.88b	68.41	43.25	24.33b	13.05b
I_2	157.53	132.51	121.91b	100.28b	68.90	43.61	23.86bc	12.46c
I_3	157.11	132.08	141.66a	115.41a	68.99	43.69	23.c	11.99d
LS	NS	NS	**	**	NS	NS	**	**
b) Variety								
V_1	156.59b	131.10b	125.56b	102.92b	68.90	43.25	23.84b	12.77b
V_2	158.44a	132.94a	127.66a	104.75a	68.18	43.28	24.88a	13.00a
LS	**	*	*	**	NS	NS	**	*
c) Mulching								
M_0	157.44	132.00	126.87	102.88	65.23c	41.32c	23.95b	12.63b
M_w	157.58	132.28	127.01	102.85	68.56b	43.68b	24.33ab	12.92b
M_s	157.25	131.89	126.03	106.85	71.55a	44.15a	24.72a	12.98b
M_p	157.80	131.91	126.55	102.75	68.81b	43.91b	24.44ab	13.00a
LS	NS	NS	NS	NS	**	**	*	*
CV (%)	3.39	3.52	2.90	2.83	3.40	2.97	3.39	3.50

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

A



B

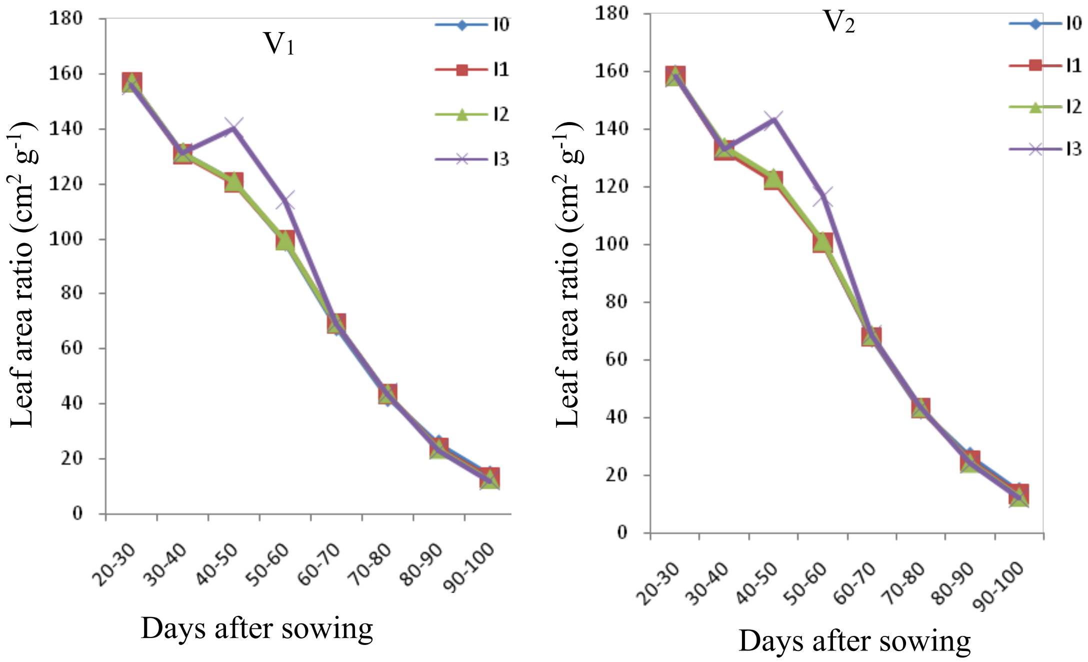
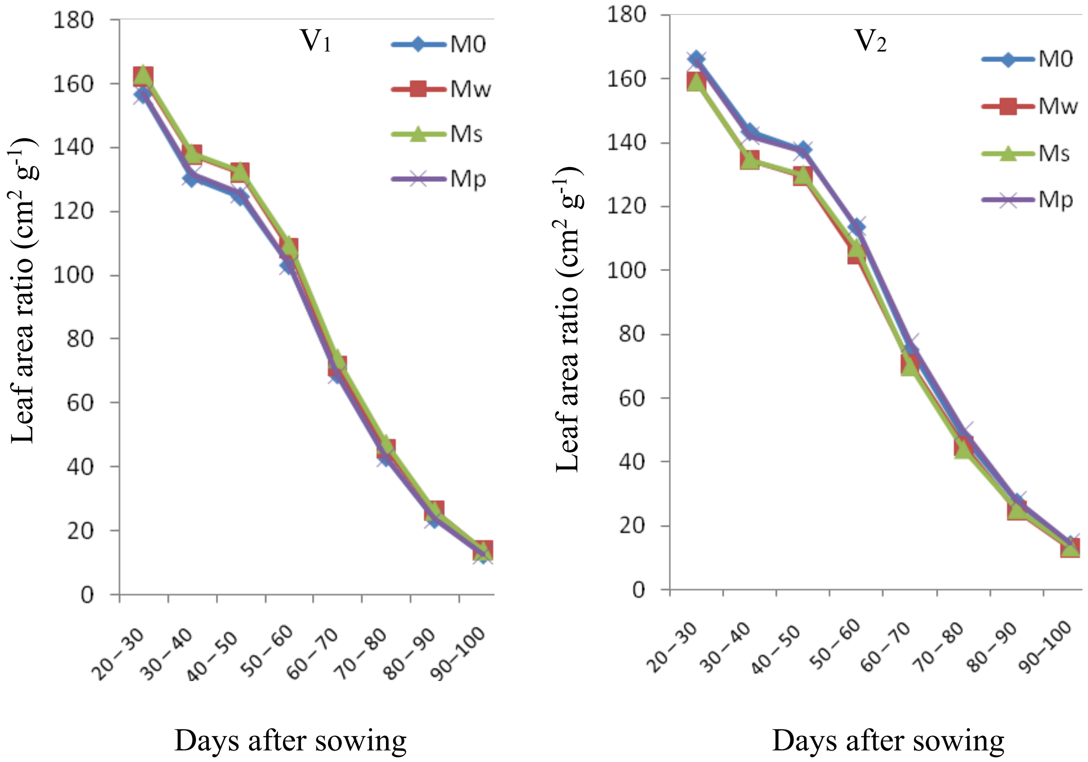


Figure 8a: Effect of irrigation levels on leaf area ratio (LAR) of two wheat varieties at different days after sowing. A 1^{st} year (2008-2009) and B 2^{nd} year (2009-2010)

A



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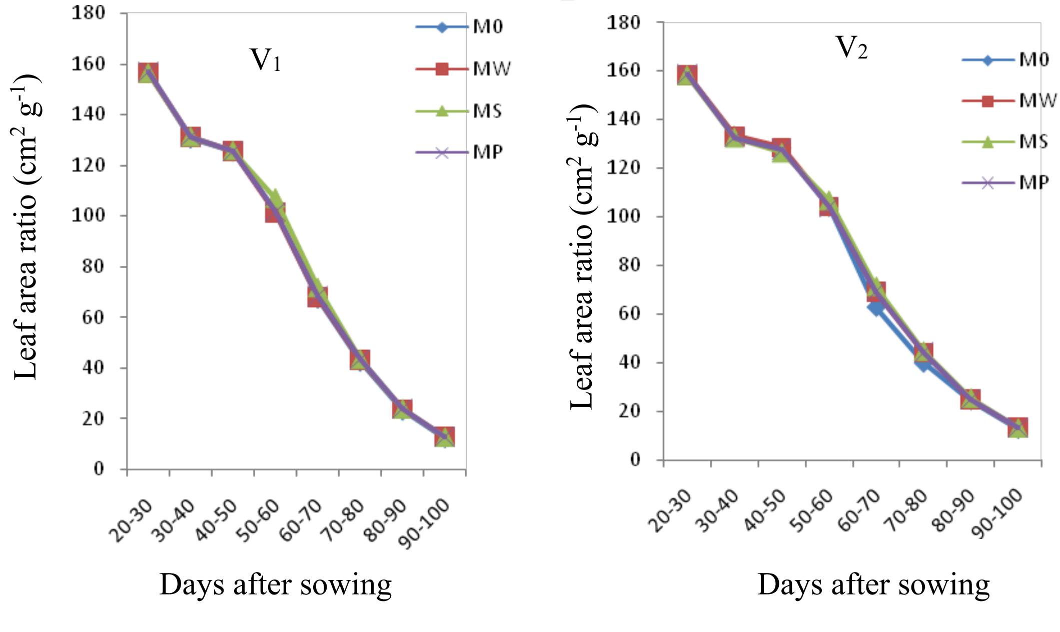

Figure 8b: Effect of mulching on leaf area ratio (LAR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.7 Relative leaf growth rate (RLGR)

Relative leaf growth rate (RLGR) was significantly influenced by different irrigation levels except at 70-80 DAS in the first year and was non-significant with few exceptions in the second year (Appendices IXa and IXb). Starting from an initial stage, RLGR decreased sharply throughout the whole growing season in both the experimental year (Fig. 9a). There was no fixed pattern of RLGR as affected by irrigation treatments. According to the Tables 2.7a and 2.7b, RLGR of all irrigation treatments became negative at 60-70 DAS. The highest RLGR was seen in I_3 and I_0treatment at 20 DAS in the first and second year respectively. The lowest RLGR was also observed in I_3 treatment at 80-90 DAS in both the years.

From the Tables 2.7a and 2.7b, it is seen that with an initial stage, both the varieties reached to the highest peak at 30-40 DAS and then it declined throughout the whole growing season. The highest RLGR was seen in both the varieties at 30-40 DAS and the lowest RLGR was observed in Sufi at 80-90 DAS.

Mulching had no significant effective on RLGR except at 60-70 DAS in the second year. It is observed from Fig. 9b that RLGR as influenced by mulching treatments started to decline from 30-40 DAS to the last harvest during the whole growing season in both the years. Tables 2.7a and 2.7b show that the highest RLGR was found at 30-40 DAS in all the mulching treatments and the lowest RLGR was in M_P and M_S treatments in the first year and M_0 and M_S treatments in the second year at 80-90 DAS.

Table 2.7a: Effect of irrigation levels, variety and mulching on RLGR (cm^2 cm^{-2} d^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
a) Irrigation levels								
I_0	0.060a	0.069a	0.045a	0.049a	- 0.001	- 0.014	- 0.050b	- 0.051b
I_1	0.057a	0.072a	0.064a	0.026b	- 0.002	- 0.014	- 0.052b	- 0.051b
I_2	0.059a	0.072a	0.064a	0.025b	- 0.002	- 0.014	- 0.054b	- 0.051b
I_3	0.066b	0.071b	0.064b	0.027b	0.000	- 0.014	- 0.061a	- 0.047a
LS	**	**	**	**	NS	NS	**	*
b) Variety								
V_1	0.060b	0.071a	0.059b	0.032a	- 0.001	- 0.015	- 0.054	- 0.049a
V_2	0.061a	0.071a	0.060a	0.031b	- 0.002	- 0.013	- 0.055	- 0.051b
LS	*	*	**	**	NS	NS	NS	*
c) Mulching								
M_0	0.060	0.071	0.059	0.033	- 0.003	- 0.013	- 0.054	- 0.050
M_w	0.061	0.071	0.060	0.030	0.000	- 0.014	- 0.054	- 0.050
M_s	0.060	0.071	0.060	0.031	- 0.003	- 0.013	- 0.055	- 0.050
M_p	0.060	0.071	0.059	0.032	0.001	- 0.017	- 0.055	- 0.050
LS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	3.55	2.21	20.33	20.49	26.02	18.46	10.68	10.82

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.7b: Effect of irrigation levels, variety and mulching on RLGR ($cm^2\ cm^{-2}\ d^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)							
	20-30	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
a) Irrigation levels								
I_0	0.060	0.070	0.046b	0.046b	-0.002	-0.014	-0.035	-0.061
I_1	0.060	0.070	0.045b	0.047a	-0.002	-0.013	-0.054	-0.046
I_2	0.060	0.072	0.044b	0.047a	-0.002	-0.013	-0.062	-0.046
I_3	0.060	0.072	0.102a	-0.012c	-0.002	-0.013	-0.067	-0.046
LS	NS	NS	**	**	NS	NS	NS	NS
b) Variety								
V_1	0.060	0.070	0.059	0.032	0.001a	-0.017	-0.054	-0.046
V_2	0.060	0.071	0.059	0.032	-0.005b	-0.010	-0.055	-0.053
LS	NS	NS	NS	NS	**	NS	NS	NS
c) Mulching								
M_0	0.061	0.070	0.060	0.029b	-0.009b	-0.004	-0.055	-0.049
M_w	0.060	0.071	0.059	0.031a	0.003a	-0.017	-0.054	-0.049
M_s	0.060	0.071	0.058	0.039a	-0.005b	-0.015	-0.055	-0.051
M_p	0.058	0.071	0.060	0.030a	0.003a	-0.017	-0.054	-0.050
LS	NS	NS	NS	NS	**	NS	NS	NS
CV (%)	13.85	8.71	9.79	16.71	24.83	17.05	14.53	15.03

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

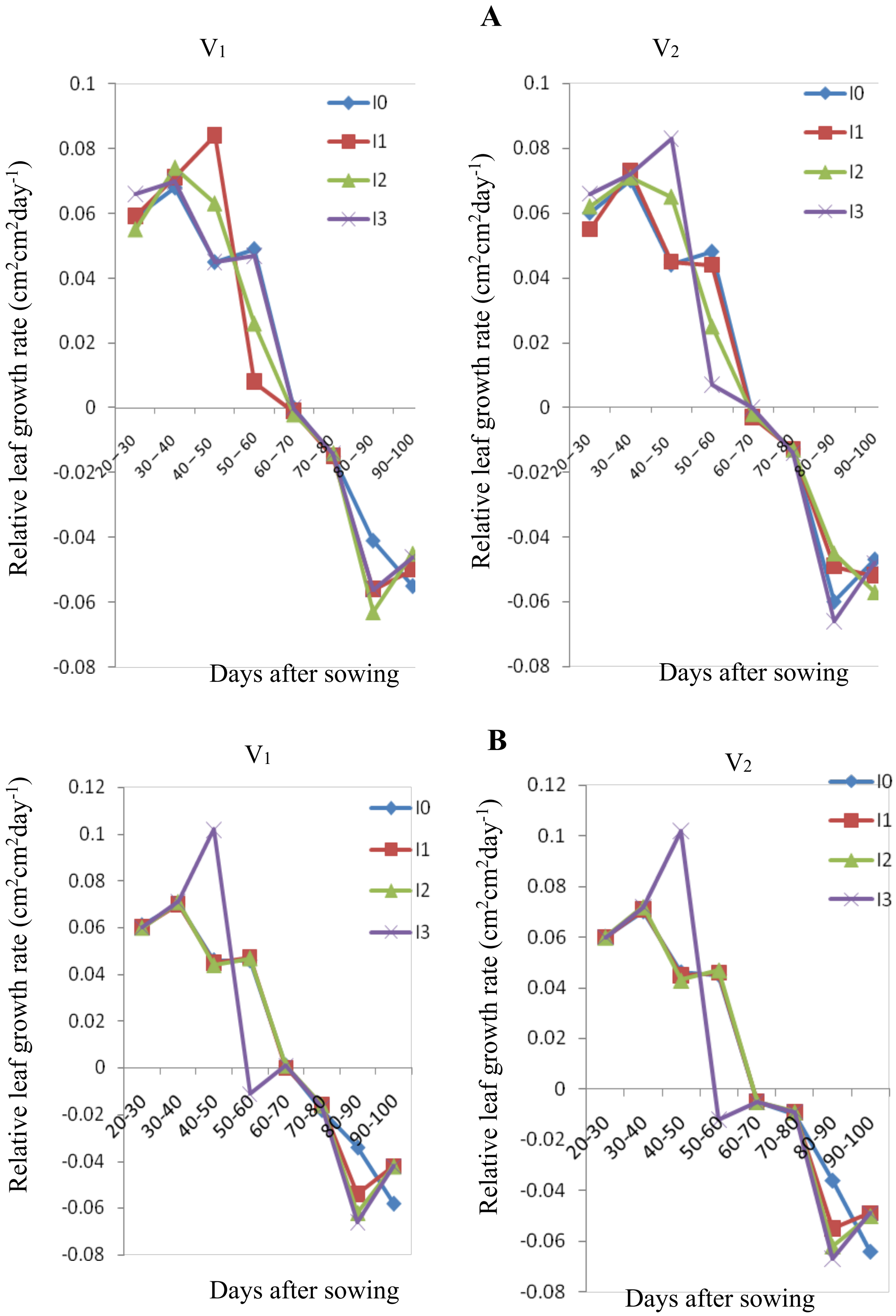

Figure 9a: Effect of irrigation levels on relative leaf growth rate (RLGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

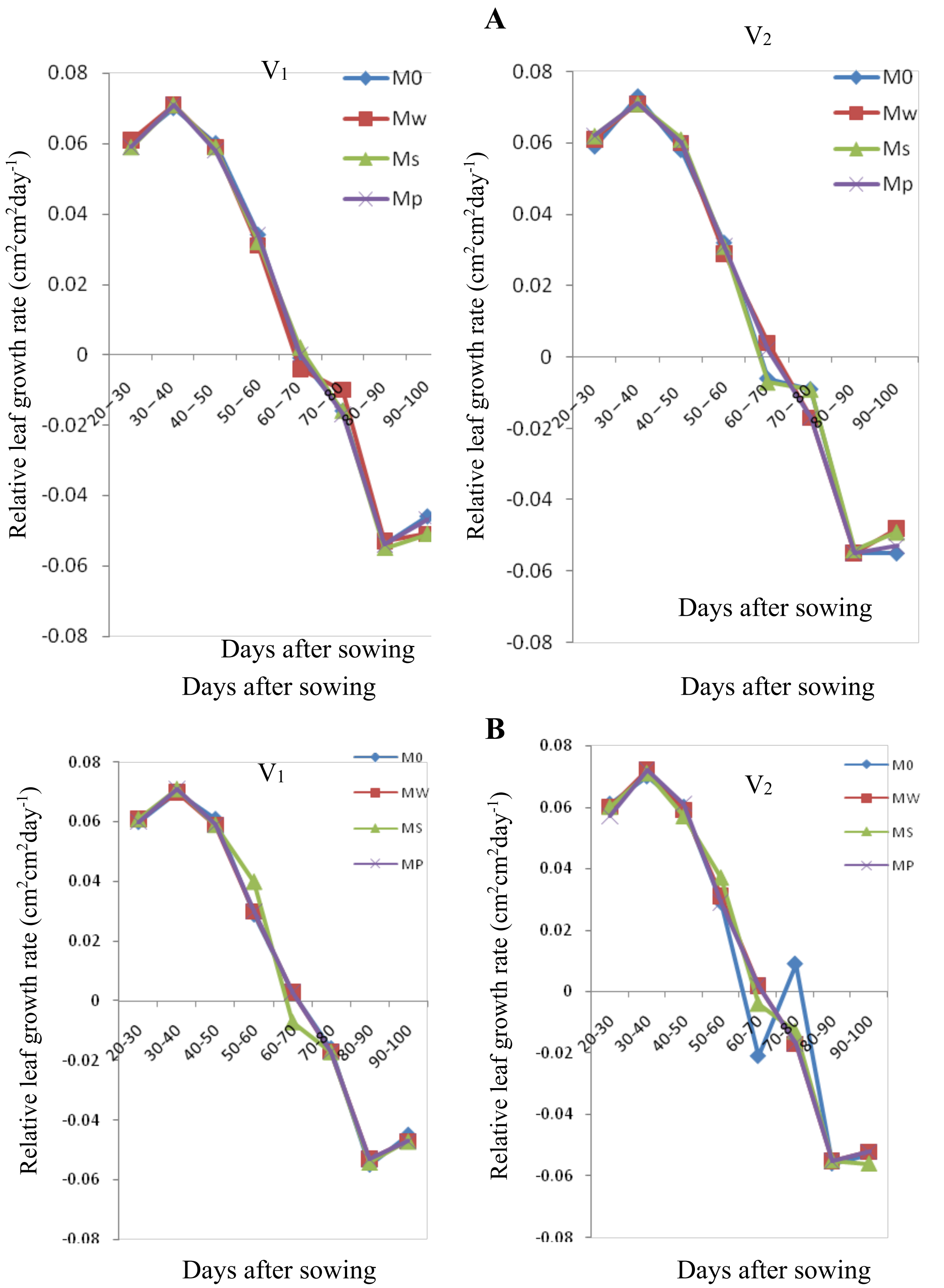

Figure 9b: Effect of mulching on relative leaf growth rate (RLGR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.8 Specific leaf area (SLA)

There was a significant influence of irrigation on specific leaf area (SLA) in the first experimental year but no specific trend of SLA values as affected by different irrigation levels (Appendices Xa and Xb) whereas in the second experimental year SLA was not significant by irrigations. Starting from the highest peak at 20 DAS, SLA influenced by irrigation decreased up to the final harvest in both the years except at 40 DAS (Fig. 10a). Tables 2.8a and 2.8b illustrate that the highest SLA was in I_0 and I_3treatments at 20 DAS in the first and second year respectively and the lowest SLA was in I_2 and I_0 treatments at 100 DAS in first and second year respectively.

Both the experimental varieties (Prodip and Sufi) also showed a declining tendency throughout the whole growing season in both the years expect at 40 DAS (Tables 2.8 and 2.8b). The highest SLA was found in Prodip at 20 DAS.

Mulching had no significant effect on SLA in both the years, except 60 DAS in the second year. Fig. 10b shows that SLA influenced by mulching treatments declined throughout the whole growing season in both the years except at 40 DAS. The highest SLA was in M_S and M_P in the first and second year respectively (Tables 2.8a and 2.8b).

Table 2.8a: Effect of irrigation levels, variety and mulching on SLA (cm^2 g^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)								
	20	30	40	50	60	70	80	90	100
a) Irrigation levels									
I_0	267.092a	249.751b	261.771c	242.975c	242.241	228.048b	221.560b	221.535ab	195.568a
I_1	264.017b	250.363b	268.267b	246.729b	241.276	225.795c	220.251b	219.817b	195.111ab
I_2	262.302b	251.496a	271.179a	248.001ab	241.122	225.570c	220.280b	219.214b	193.908b
I_3	266.948a	252.306a	269.991a	249.015a	242.648	231.735a	225.605a	223.663a	195.951a
LS	**	**	**	**	NS	**	**	**	*
b) Variety									
V_1	265.352a	250.871	266.571b	245.966b	241.933	227.669	222.050a	221.540a	195.395
V_2	264.827b	251.087	269.033a	247.394a	241.711	227.905	221.798b	220.574b	194.874
LS	*	NS	**	**	NS	NS	*	*	NS
c) Mulching									
M_0	264.704	250.668	267.853	246.316	243.827	227.332	222.014	220.752	194.741
M_W	264.503	250.821	266.885	246.037	235.475	228.120	221.481	220.890	195.114
M_S	265.743	251.077	267.882	247.239	243.662	227.811	221.773	220.780	194.694
M_P	265.408	251.350	268.587	247.128	244.323	227.885	222.429	221.807	195.988
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	1.02	0.49	0.78	0.96	6.18	0.74	0.93	1.51	1.40

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation, I_1 = 2 cm of irrigation, I_2 = 4 cm of irrigation, I_3 = 6 cm of irrigation
Variety : V_1 = Prodip, V_2 = Sufi
Mulching : M_0 = no mulching, M_W = water hyacinth, M_S = rice straw, M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.8b: Effect of irrigation levels, variety and mulching on SLA ($cm^2\ g^{-1}$) of wheat in 2009-2010

Treatment	Days after sowing (DAS)								
	20	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
a) Irrigation levels									
I_0	265.21	250.84	266.65	246.32	240.40d	224.13	220.56	219.58	194.77
I_1	266.11	250.96	265.51	245.96	241.49c	225.81	222.29	221.46	196.16
I_2	266.16	252.06	268.72	246.51	243.46b	227.21	223.12	222.15	195.66
I_3	266.17	251.53	269.39	246.40	244.34a	227.72	223.32	221.88	196.19
LS	NS	NS	NS	NS	*	NS	NS	NS	NS
b) Variety									
V_1	266.02	251.26	267.25	246.44	242.22	227.52	222.31	221.40	195.44
V_2	265.80	251.43	267.88	246.16	242.63	224.91	222.34	221.14	195.95
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS
c) Mulching									
M_0	264.50	251.59	267.31	246.83	235.12d	225.75	222.04	218.84	195.02
M_W	265.95	251.21	266.89	246.06	235.79c	225.87	222.82	221.12	196.08
M_S	265.65	251.13	268.09	245.61	261.71b	226.26	223.61	222.31	195.33
M_P	267.54	251.46	267.98	246.68	237.07a	226.98	220.83	222.80	196.34
LS	NS	NS	NS	NS	**	NS	NS	NS	NS
CV (%)	4.53	4.21	2.84	2.69	4.12	3.43	4.52	3.28	3.00

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation, I_1 = 2 cm of irrigation, I_2 = 4 cm of irrigation, I_3 = 6 cm of irrigation
Variety : V_1 = Prodip, V_2 = Sufi
Mulching : M_0 = no mulching, M_W = water hyacinth, M_S = rice straw, M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

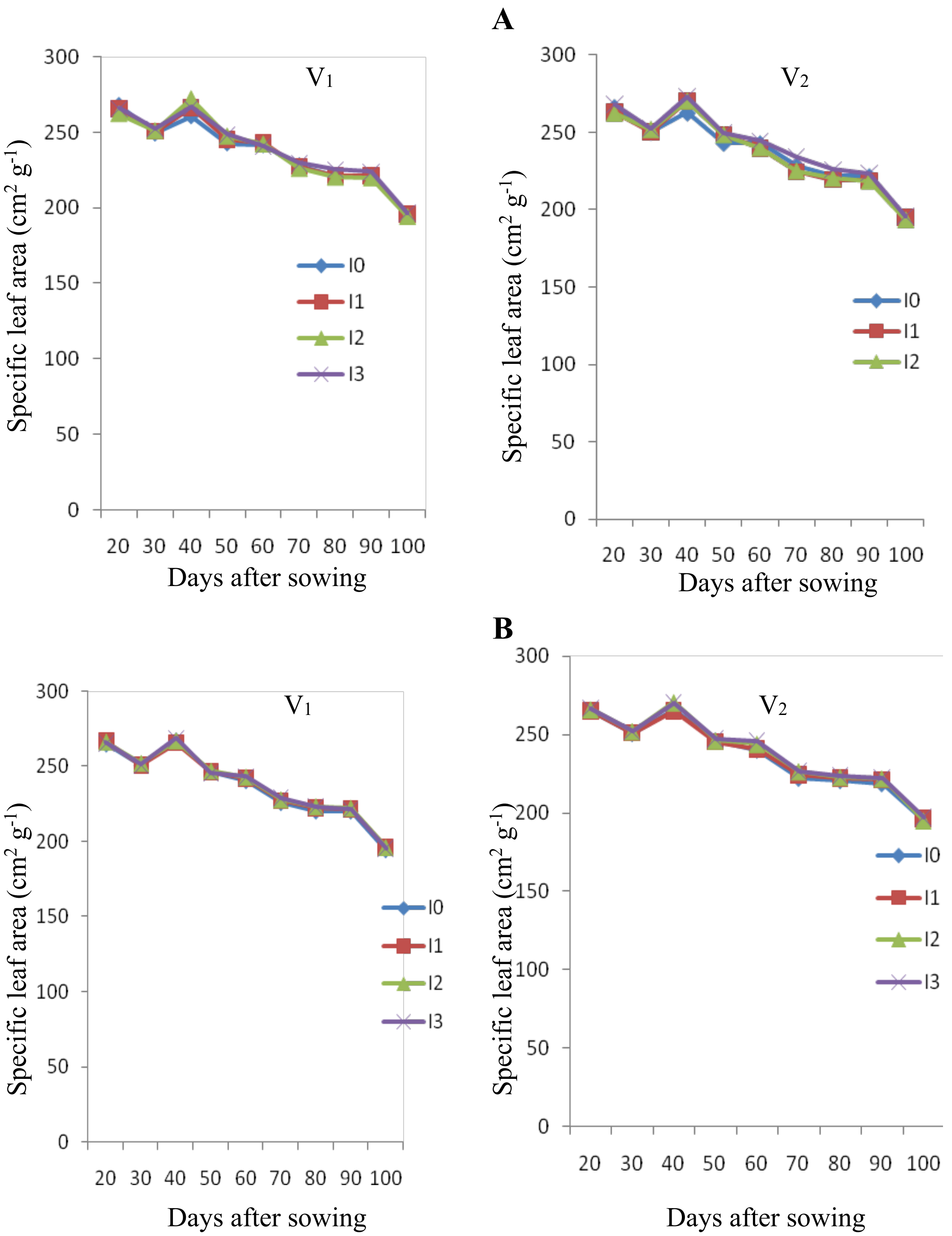

Figure 10a: Effect of irrigation levels on specific leaf area (SLA) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

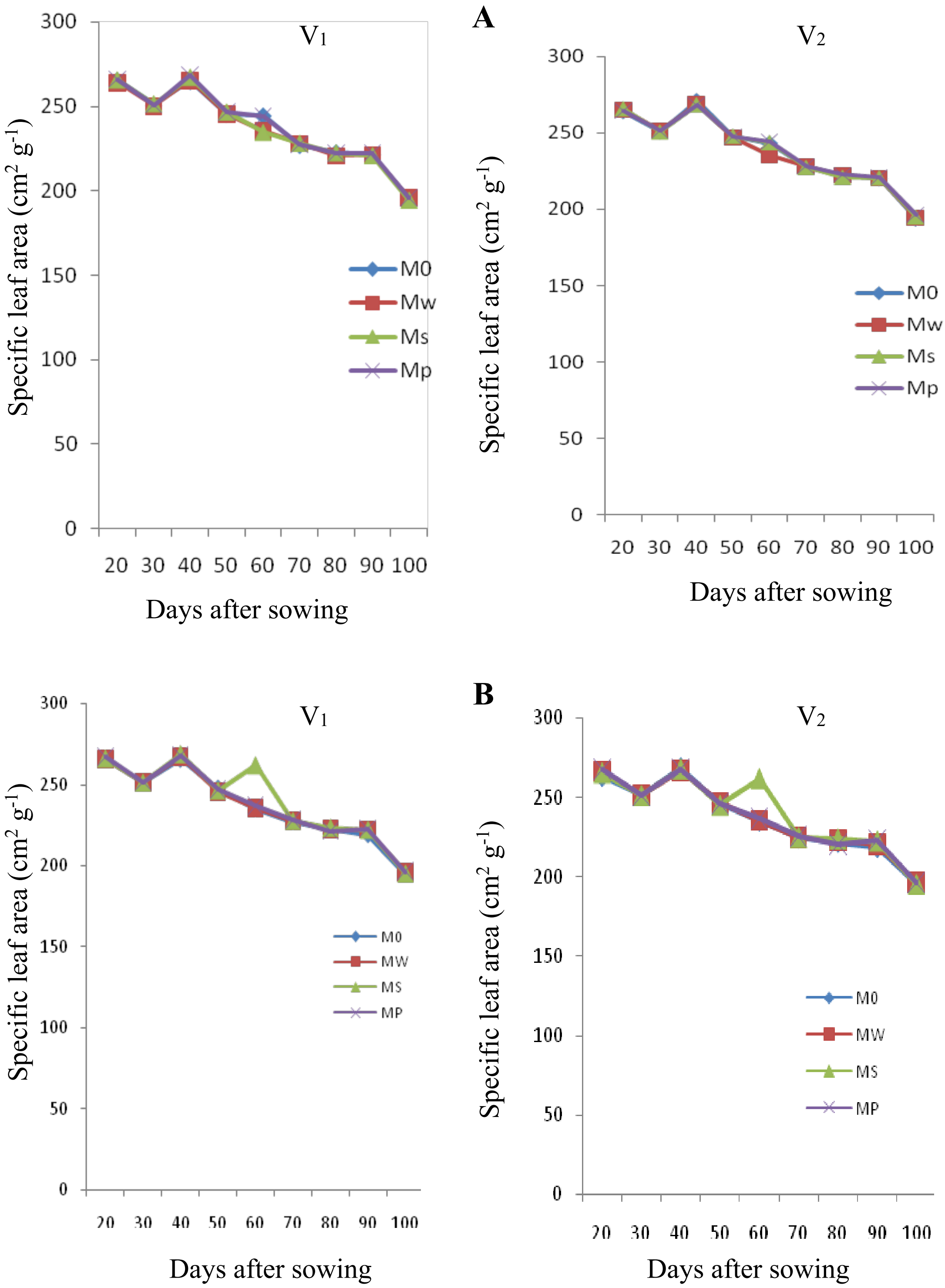

Figure 10b: Effect of mulching on specific leaf area (SLA) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.2.9 Leaf weight ratio (LWR)

Figure 11a shows that LWR influenced by irrigation treatments declined throughout the whole growing season in both the varieties (Appendices XIa and XIb). In both the years, it was non-significant with a few exceptions. Tables 2.9a and 2.9b reveal that there was no specific pattern of LWR. The highest LWR was in I_0 and I_1 treatments in the first year and I_0 treatment in second year at 20 DAS and the lowest LWR was in I_2 and I_3treatments at 100 DAS in the first and second year, respectively.

Between the varieties, the highest LWR was found in Sufi at 20 DAS and the lowest LWR was observed in Prodip at in first year and Sufi in the second year at 100 DAS (Tables 2.9a and 2.9b).

As influenced by different mulching treatments, LAR of both the varieties declined from the highest peak at the first harvest throughout the whole growing season (Fig. 11b). The highest LWR was found in M_0 at 20 DAS and the lowest LWR was found in all the mulching treatments at 100 DAS (Tables 2.9a and 2.9b).

Table 2.9a: Effect of irrigation levels, variety and mulching on LWR (g g^{-1}) of wheat in 2008-2009

Treatment	Days after sowing (DAS)								
	20	30	40	50	60	70	80	90	100
a) Irrigation levels									
I_0	0.748a	0.551	0.505	0.480b	0.387	0.250	0.168	0.082	0.054
I_1	0.748a	0.552	0.508	0.531a	0.387	0.249	0.167	0.080	0.053
I_2	0.746a	0.549	0.507	0.530a	0.386	0.248	0.166	0.079	0.052
I_3	0.732b	0.545	0.504	0.531a	0.388	0.251	0.169	0.075	0.053
LS	**	NS	NS	**	NS	NS	NS	NS	NS
b) Variety									
V_1	0.739b	0.543b	0.499b	0.510b	0.380b	0.246b	0.163b	0.077b	0.052b
V_2	0.748a	0.556a	0.513a	0.526a	0.394a	0.253a	0.171a	0.081a	0.054a
LS	*	**	**	*	**	**	**	*	**
c) Mulching									
M_0	0.745	0.551	0.508	0.517	0.387	0.248	0.167	0.079	0.053
M_W	0.743	0.549	0.506	0.518	0.389	0.248	0.167	0.079	0.053
M_S	0.742	0.549	0.505	0.518	0.385	0.247	0.168	0.079	0.053
M_P	0.743	0.548	0.506	0.517	0.386	0.255	0.168	0.079	0.053
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	2.22	3.43	3.81	6.71	4.82	7.40	6.78	8.43	4.26

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.9b: Effect of irrigation levels, variety and mulching on LWR (g g^{-1}) of wheat in 2009-2010

Treatment	Days after sowing (DAS)								
	20	30	40	50	60	70	80	90	100
a) Irrigation levels									
I_0	0.735	0.535	0.489	0.466	0.370	0.236	0.156b	0.088a	0.051a
I_1	0.734	0.533	0.489	0.465	0.370	0.237	0.158a	0.074b	0.052a
I_2	0.733	0.530	0.490	0.464	0.370	0.237	0.159a	0.070c	0.050a
I_3	0.732	0.529	0.487	0.608	0.369	0.237	0.159a	0.067d	0.048b
LS	NS	NS	NS	NS	NS	NS	**	**	**
b) Variety									
V_1	0.729b	0.529b	0.486b	0.496b	0.367	0.240a	0.155b	0.073b	0.051a
V_2	0.738a	0.535a	0.492a	0.505a	0.373	0.234b	0.162a	0.077a	0.050b
LS	**	**	**	**	NS	**	**	**	*
c) Mulching									
M_0	0.735	0.532	0.488	0.502	0.373a	0.220	0.157	0.074	0.050
M_W	0.733	0.533	0.491	0.503	0.372a	0.242	0.157	0.075	0.050
M_S	0.733	0.531	0.488	0.498	0.364b	0.242	0.160	0.076	0.050
M_P	0.733	0.531	0.488	0.499	0.371a	0.242	0.160	0.075	0.051
LS	NS	NS	NS	NS	**	NS	NS	NS	NS
CV (%)	1.38	2.48	2.21	2.34	1.81	3.25	3.54	3.82	4.04

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

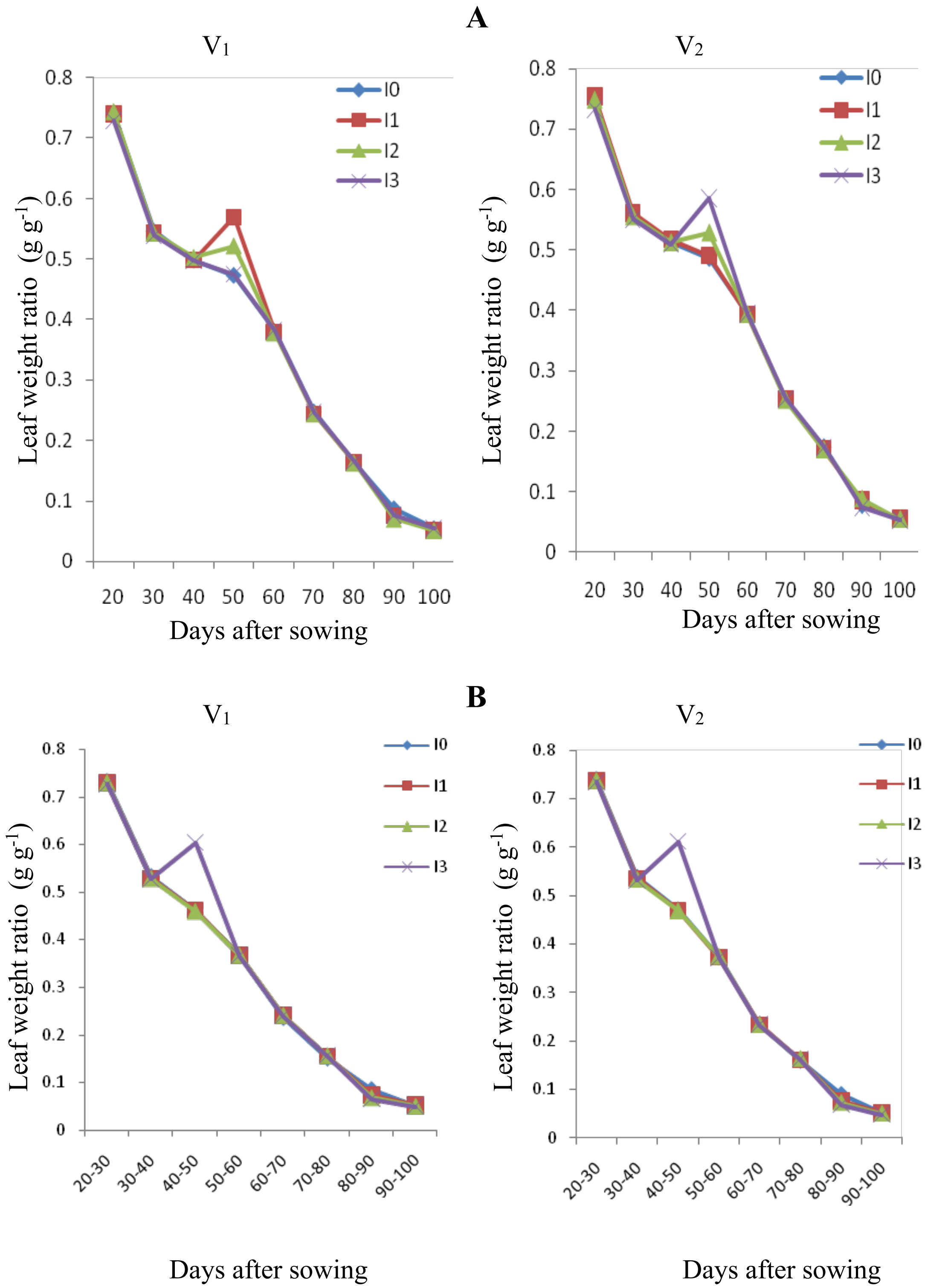

Figure 11a: Effect of irrigation levels on leaf weight ratio (LWR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

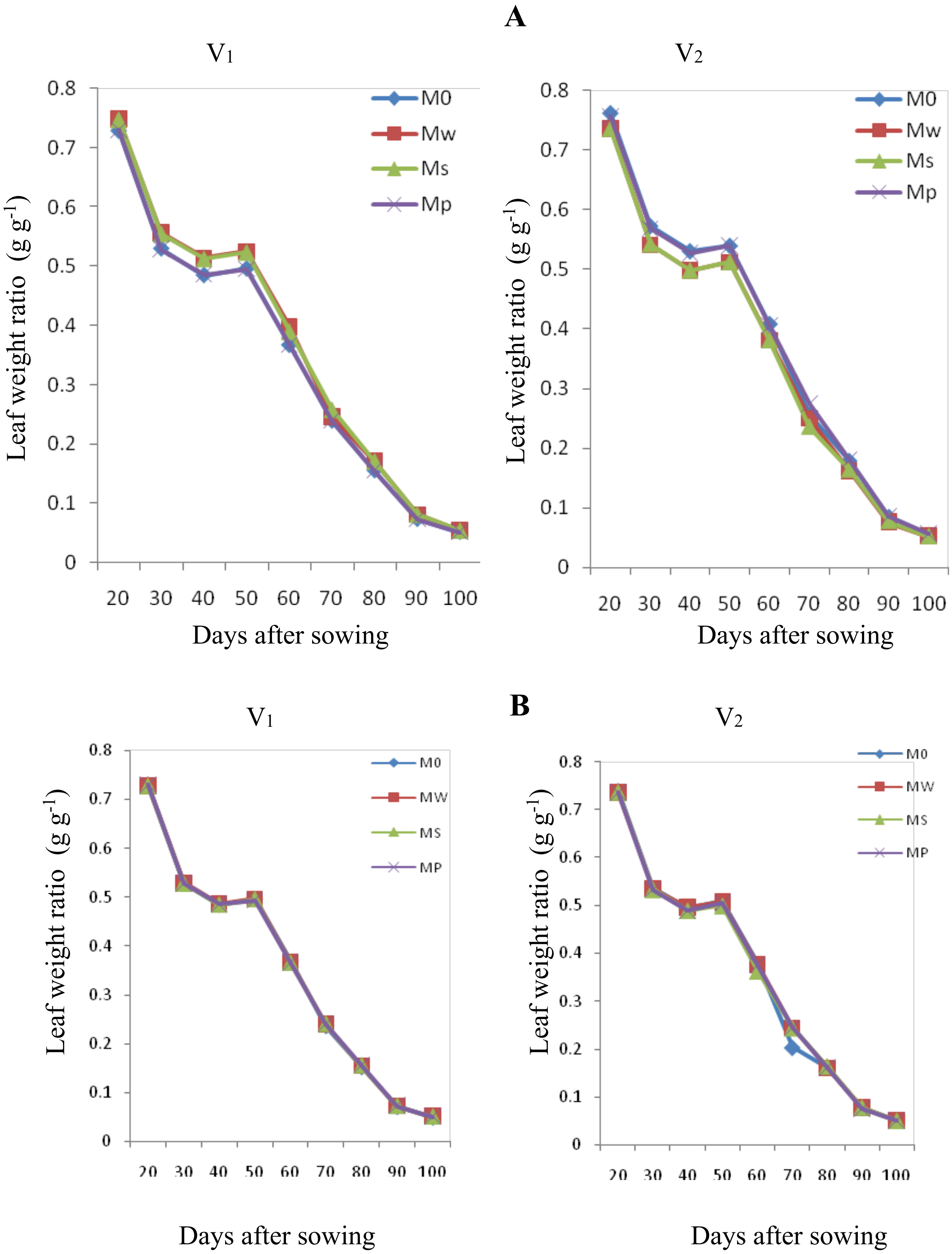

Figure 11b: Effect of mulching on leaf weight ratio (LWR) of two wheat varieties at different days after sowing. A 1st year (2008-2009) and B 2nd year (2009-2010)

4.3 WATER RELATION

4.3.1 Moisture retention capacity (MRC)

The effect of different irrigation levels, varieties and mulching treatments was found to be significant in both the experimental years (Appendices XIIa and XIIb). Tables 2.10a and 2.10b reveal that early hours in the observed day had higher moisture retention capacity in all the values of irrigation, variety and mulching and the values steadily decreased with the advancement of time in the day. The highest MRC influenced by irrigation was in I_3 at 8:30 AM and the lowest MRC was in I_0 at 3:00 PM. Thus, it is understood that higher irrigation levels had higher in MRC in both the years.

Between the two wheat varieties, Prodip had higher MRC throughout the day (Tables 2.10a and 2.10b). However, the highest MRC was in Prodip at 8:30 AM and the lowest MRC was in Sufi at 3:00 PM in both the years.

Mulching had also significant effect on the flag leaf of wheat in both the years (Tables 2.10a and 2.10b). M_P had the highest MRC at 8:30 AM followed by M_S and M_W. The lowest MRC was found in M_0 at 3:00 PM in both the experimental years.

The interaction effect of irrigation and mulching was not found significant (Tables 2.11a and 2.11b). The highest MRC was found in the combination effect of $I_3 \times M_P$ at 8:30 PM followed by $I_3 \times M_w$ in both the years. The lowest combination effect of irrigation and mulching was found in $I_0 \times M_0$ at 3:00 PM.

Table 2.10a: Effect of irrigation levels, variety and mulching on moisture retention capacity (%) of flag leaf of wheat in 2008-2009

Treatments	Time of the day									
	8:30 am	**9:00 am**	**9:30 am**	**10:00 am**	**10:30 am**	**11:00 am**	**12:00 pm**	**1:00 pm**	**2:00 pm**	**3:00 pm**
a) Irrigation levels										
I_0	69.10d	65.71d	64.14d	63.07d	62.68c	60.74c	58.87c	56.65d	56.11c	52.80c
I_1	71.67c	68.20c	66.70c	65.49c	63.55c	62.15bc	59.61c	58.86c	57.04c	54.69c
I_2	74.01b	70.56b	69.33b	68.69b	66.96b	63.40b	62.85b	61.69b	60.72b	57.19b
I_3	77.85a	75.07a	75.48a	72.84a	70.80a	67.30a	66.96a	65.58a	64.61a	61.22a
LS	**	**	**	**	**	**	**	**	**	**
b) Variety										
V_1	77.07a	74.07a	72.85a	71.03a	69.40a	67.43a	65.42a	63.97a	62.82a	59.53a
V_2	69.25b	65.70b	64.98b	64.01b	62.60b	59.36b	58.73b	57.42b	56.42b	53.42b
LS	**	**	**	**	**	**	**	**	**	**
c) Mulching										
M_0	67.62d	65.25c	64.33c	62.34c	60.49d	59.16c	56.54d	55.47c	53.60c	51.63c
M_w	72.19c	69.51b	68.53b	66.83c	65.07c	60.78c	61.15c	59.96b	58.41b	56.21b
M_s	74.82b	71.27b	70.38ab	69.56b	67.94b	65.47b	63.53b	62.69a	62.29a	57.77b
M_p	78.02a	73.52a	72.41a	71.36a	70.49a	68.17a	67.07a	64.67a	64.18a	60.29a
LS	**	**	**	**	**	**	**	**	**	**
CV (%)	4.10	4.14	4.05	3.92	4.06	4.11	4.06	4.36	4.79	5.32

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance CV = Coefficient of Variation

Table 2.10b: Effect of irrigation levels, variety and mulching on moisture retention capacity (%) of flag leaf of wheat in 2009-2010

Treatments	Time of the day									
	8:30 am	9:00 am	9:30 am	10:00 am	10:30 am	11:00 am	12:00 pm	1:00 pm	2:00 pm	3:00 pm
a) Irrigation levels										
I_0	69.07d	66.58c	64.14d	64.07c	62.70c	60.85c	57.77c	56.65d	55.23d	52.72c
I_1	71.61c	68.19bc	66.61c	64.79c	63.59c	61.33c	58.57c	58.81c	57.80c	54.70c
I_2	73.95b	69.80b	69.27b	68.85b	66.97b	64.19b	61.73b	61.55b	60.87b	57.18b
I_3	77.66a	75.10a	75.45aa	73.18a	70.88a	67.40a	66.08a	65.73a	64.58a	61.11a
LS	**	**	**	**	**	**	**	**	**	**
b) Variety										
V_1	76.93a	74.12a	72.76a	71.29a	69.50a	67.50a	64.42a	63.94a	62.85a	59.50a
V_2	69.21b	65.71b	64.97b	64.15b	62.56b	59.39b	57.64b	57.43b	56.38b	53.36b
LS	**	**	**	**	**	**	**	**	**	**
c) Mulching										
M_0	67.72d	65.33c	64.40c	62.50c	60.45d	58.37d	55.56d	55.43c	53.50c	51.56c
M_w	72.06c	69.49b	68.49b	66.92b	65.13c	61.58c	60.11c	59.94b	58.55b	56.24b
M_s	74.65b	71.30b	70.22b	69.76a	67.83b	65.41b	62.32b	62.68a	62.34a	57.76b
M_p	77.84a	73.54a	72.36a	71.71a	70.72a	68.42a	66.14a	64.69a	64.08a	60.15a
LS	**	**	**	**	**	**	**	**	**	**
CV (%)	3.50	3.87	3.62	4.56	4.47	4.61	4.44	4.46	4.90	5.39

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene

LS = Level of Significance CV = Coefficient of Variation

Table 2.11a: Interaction effect of irrigation levels and mulching on moisture retention capacity (%) of flag leaf of wheat in 2008-2009

Treatments	Time of the day									
	8:30 am	9:00 am	9:30 am	10:00 am	10:30 am	11:00 am	12:00 pm	1:00 pm	2:00 pm	3:00 pm
I_0M_0	61.615	59.865	58.387	56.980	58.520	56.422h	54.610	50.680	51.565	47.180
I_0M_w	68.515	65.622	64.362	63.027	61.448	59.272fgh	57.540	56.510	54.858	52.878
I_0M_s	71.527	67.608	66.023	65.550	64.238	62.187def	59.737	58.703	58.495	54.490
I_0M_p	74.760	69.750	67.767	66.713	66.527	65.088cd	63.585	60.720	59.523	56.647
I_1M_0	67.078	64.657	62.848	61.570	56.330	57.532gh	52.747	54.737	50.073	51.013
I_1M_w	70.218	67.865	66.225	64.638	63.158	60.603efg	59.428	57.820	56.513	54.233
I_1M_s	73.030	69.142	68.168	67.347	66.468	64.410cde	61.558	60.732	60.388	55.608
I_1M_p	76.365	71.142	69.572	68.413	68.228	66.045bcd	64.708	62.165	61.180	57.922
I_2M_0	69.518	67.068	66.205	63.950	61.987	60.035fgh	58.045	56.923	55.145	52.950
I_2M_w	72.890	70.415	69.008	67.795	65.997	56.620h	62.073	61.000	59.777	57.408
I_2M_s	75.703	71.903	70.807	70.990	69.050	67.357bc	64.382	64.322	63.513	58.705
I_2M_p	77.928	72.855	71.287	72.022	70.790	69.572ab	66.885	64.532	64.435	59.678
I_3M_0	72.248	69.393	69.875	66.863	65.110	62.667def	60.753	59.527	57.627	55.363
I_3M_w	77.150	74.125	74.505	71.848	69.685	66.640bc	65.555	64.507	62.503	60.330
I_3M_s	79.000	76.440	76.518	74.352	72.012	67.908bc	68.423	67.020	66.743	62.282
I_3M_p	83.017	80.320	81.007	78.283	76.398	71.992a	73.118	71.247	71.562	66.918
LS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS
CV (%)	4.10	4.14	4.05	3.92	4.06	4.11	4.06	4.36	4.79	5.32

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.11b: Interaction effect of irrigation levels and mulching on moisture retention capacity (%) of flag leaf of wheat in 2009-2010

Treatments	Time of the day									
	8:30 am	**9:00 am**	**9:30 am**	**10:00 am**	**10:30 am**	**11:00 am**	**12:00 pm**	**1:00 pm**	**2:00 pm**	**3:00 pm**
I_0M_0	62.263	63.660	58.922	60.562	58.645	56.412	53.543	50.657	48.232	46.697
I_0M_w	68.228	65.575	64.322	63.362	61.538	59.438	56.445	56.547	54.880	53.097
I_0M_s	71.072	67.568	65.783	65.677	64.045	61.978	58.593	58.805	58.430	54.503
I_0M_p	74.733	69.510	67.522	66.673	66.570	65.583	62.477	60.600	59.387	56.587
I_1M_0	66.993	64.567	62.590	58.280	56.133	54.155	52.060	54.507	53.033	51.025
I_1M_w	70.290	67.870	66.330	64.688	63.445	60.428	58.485	57.858	56.552	53.992
I_1M_s	73.077	69.103	68.100	67.597	66.290	64.445	60.208	60.825	60.467	55.787
I_1M_p	76.058	71.200	69.415	68.580	68.472	66.303	63.510	62.055	61.130	57.975
I_2M_0	69.487	63.798	66.128	64.145	61.950	60.133	56.883	56.923	55.197	53.042
I_2M_w	72.862	70.408	68.863	67.948	65.983	59.792	60.982	60.805	60.210	57.590
I_2M_s	75.532	72.122	70.695	71.323	68.875	67.352	63.300	64.092	63.442	58.610
I_2M_p	77.908	72.873	71.407	71.987	71.055	69.482	65.735	64.378	64.623	59.490
I_3M_0	72.142	69.308	69.938	66.997	65.067	62.778	59.767	59.630	57.555	55.470
I_3M_w	76.877	74.118	74.435	71.697	69.552	66.660	64.540	64.553	62.555	60.283
I_3M_s	78.937	76.390	76.315	74.445	72.115	67.852	67.172	67.010	67.012	62.118
I_3M_p	82.665	80.578	81.090	79.580	76.795	72.305	72.828	71.720	71.188	66.562
LS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	3.50	3.87	3.62	4.56	4.47	4.61	4.44	4.46	4.90	5.39

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation

Mulching : M_0 = no mulching M_W = water hyacinth M_S = rice straw M_P = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

4.3.2 Relative leaf water content (RLWC)

Tables 2.12a and 2.12b show that the effect of irrigation on RLWC of the flag leaf of wheat was significant (Appendices XIIIa and XIIIb). Starting from the highest peak at 8:00 AM. RLWC declined at 12:00 PM and again increased at 4:00 PM in both the years. It is also observed that higher levels of irrigation had higher RLWC over lower levels of irrigation.

Variety had a significant effect on RLWC of the flag leaf of wheat (Tables 2.12a and 2.12b). Prodip had highest RLWC at 8:00 AM and Sufi had the lowest RLWC at 12:00 PM every year.

The influence of mulching had also a significant effect on RLWC of the flag leaf of wheat (Tables 2.12a and 2.12b). The highest value of RLWC of the flag leaf of wheat as influenced by mulcing was in M_P treatment at 8:00 AM followed by M_S and M_W. The lowest RLWC of the flag leaf of wheat was found in M_0 treatment at 12:00 PM.

There was no significant combination effect of irrigation and mulching on the flag leaf of wheat except at 4.00 PM (Tables 2.13a and 2.13b). The highest value of RLWC of the flag leaf of wheat influenced by irrigation and mulching was found in $I_3 \times M_P$ followed by $I_3 \times M_S$ and $I_3 \times M_W$ at 8:00 AM and the lowest value was found in $I_0 \times M_0$ treatment combination at 12:00 PM in both the years. Tables 1.12a and 1.12b show that the effect of irrigation on RLWC of the flag leaf of wheat was significant. Starting from the highest peak at 8:00 AM. RLWC declined at 12:00 PM and again increased at 4:00 PM in both the years. It is also observed that higher levels of irrigation had higher RLWC over lower levels of irrigation.

Variety had a significant effect on RLWC of the flag leaf of wheat (Tables 1.12a and 1.12b). Prodip had the highest RLWC at 8:00 AM and Sufi had the lowest RLWC at 12:00 PM in both the years.

The influence of mulching had also a significant effect on RLWC of the flag leaf of wheat (Tables 1.12a and 1.12b). The highest value of RLWC of the flag leaf of wheat was in M_P treatment at 8:00 AM followed by M_S and M_W. The lowest RLWC of the flag leaf of wheat was found in M_0 treatment at 12:00 PM.

There was a significant combination effect of irrigation and mulching on the flag leaf of wheat (Tables 1.13a and 1.13b). The highest value of RLWC of the flag leaf of wheat influenced by irrigation and mulching was found in $I_3 \times M_P$ followed by $I_3 \times M_S$ and $I_3 \times M_W$ at 8:00 AM and the lowest value was found in $I_0 \times M_0$ treatment combination at 12:00 PM in both the years.

Table 2.12a: Effect of irrigation levels, variety and mulching on relative leaf water content (%) of flag leaf of wheat in 2008-2009

Treatments	Time of the day		
	8:00 am	12:00 pm	4:00 pm
a) Irrigation level			
I_0	75.617c	58.107c	73.671c
I_1	78.854d	60.832d	76.467d
I_2	82.130b	63.650b	80.641b
I_3	86.245a	67.652a	85.023a
LS	**	**	**
b) Variety			
V_1	84.737a	66.460a	83.188a
V_2	76.686b	58.660b	74.713b
LS	**	**	**
c) Mulching			
M_0	75.296c	59.150c	74.860c
M_w	80.012d	62.427b	78.160b
M_s	82.435b	63.272b	80.503a
M_p	85.103a	65.391a	82.279a
LS	**	**	**
CV (%)	2.14	3.82	2.99

Table 2.12b: Effect of irrigation levels, variety and mulching on relative leaf water content (%) of flag leaf of wheat in 2009-2010

Treatments	Time of the day		
	8:00 am	12:00 pm	4:00 pm
a) Irrigation level			
I_0	77.609c	60.910d	73.733c
I_1	80.555d	63.358c	78.806d
I_2	83.812b	66.101b	81.755b
I_3	88.564a	69.755a	86.607a
LS	**	**	**
b) Variety			
V_1	86.775a	68.782a	84.535a
V_2	78.495b	61.280b	75.915b
LS	**	**	**
c) Mulching			
M_0	76.765d	60.470c	75.602c
M_w	81.206c	64.004d	79.402d
M_s	85.255b	66.204b	81.786b
M_p	87.315a	69.445a	84.110a
LS	**	**	**
CV (%)	2.89	3.73	2.84

Table 2.13a: Interaction effect of irrigation levels and mulching on relative leaf water content (%) of flag leaf of wheat in 2008-2009

Treatments	Time of the day		
	8:00 am	12:00 pm	04:00 pm
I_0M_0	69.89	54.55	72.03h
I_0M_W	75.46	59.04	72.34h
I_0M_S	77.44	58.33	74.14gh
I_0M_P	79.68	60.52	76.19fg
I_1M_0	73.97	58.46	72.18h
I_1M_W	78.11	60.39	76.54fg
I_1M_S	80.23	61.34	78.55ef
I_1M_P	83.10	63.14	78.60ef
I_2M_0	77.06	60.69	76.48fg
I_2M_W	81.54	63.45	80.29de
I_2M_S	83.81	64.56	82.38cd
I_2M_P	86.12	65.90	83.42c
I_3M_0	80.27	62.91	78.76ef
I_3M_W	84.94	66.83	83.47c
I_3M_S	88.26	68.86	86.95b
I_3M_P	91.51	72.00	90.91a
LS	NS	NS	*
CV (%)	2.14	3.82	2.99

Table 2.13b: Interaction effect of irrigation levels and mulching on relative leaf water content (%) of flag leaf of wheat in 2009-2010

Treatments	Time of the day		
	8:00 am	12:00 pm	04:00 pm
I_0M_0	70.75	56.23	69.75j
I_0M_W	75.86	59.81	73.62i
I_0M_S	82.40	62.08	74.99hi
I_0M_P	81.42	65.53	76.57ghi
I_1M_0	75.90	59.92	75.39hi
I_1M_W	79.67	62.69	78.00fgh
I_1M_S	81.98	64.37	80.26efg
I_1M_P	84.67	66.45	81.58cdef
I_2M_0	78.56	62.19	77.34ghi
I_2M_W	82.89	64.99	81.32def
I_2M_S	85.49	67.29	83.20cde
I_2M_P	88.31	69.94	85.16bc
I_3M_0	81.85	63.54	79.93efg
I_3M_W	86.40	68.54	84.67cd
I_3M_S	91.14	71.08	88.69b
I_3M_P	94.86	75.86	93.13a
LS	NS	NS	*
CV (%)	2.89	3.73	2.84

4.4 BIOCHEMICAL CHARACTER

4.4.1 Chlorophyll content

Chlorophyll content of flag leaf of wheat was significantly affected by different irrigation levels (Appendices XIVa and XIVb). Tables 2.14a and 2.14b shows that irrigated plants had higher chlorophyll a, chlorophyll b and total chlorophyll than non-irrigated or rain-fed plants. The highest chlorophyll a, chlorophyll b and total chlorophyll were in the I_3 treatment followed by I_2, I_1 and I_0. The chlorophyll ratios of both years were insignificant as affected by different irrigation levels. The highest chlorophyll a:b ratio was observed in I_0 treatment in both the experimental years.

Chlorophyll a. chlorophyll b, total chlorophyll and chlorophyll a:b ratio were significantly affected by both the varieties (Tables 2.14a and 2.14b). Prodip contained the higher values of chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a:b ratio, compared to Sufi.

Chlorophyll a. chlorophyll b, total chlorophyll and chlorophyll a:b ratio was significantly influenced by different mulching treatments in both the experimental years (Tables 2.14a and 2.14b). Black polythene mulch (M_P) produced plants containing the highest chlorophyll a, chlorophyll b and total chlorophyll followed by rice straw (M_S) and water hyacinth (M_W). The highest and the lowest chlorophyll a:b ratios were found in M_0 and M_P, respectively.

The significant interaction effect of irrigation and mulching was only observed in flag leaves of wheat containing chlorophyll a (Tables 2.15a and 2.15b). The other interaction effects such as chlorophyll b, total chlorophyll and chlorophyll a:b ratio was insignificant. In the first experimental year, the highest chlorophyll a and total chlorophyll were observed in $I_3 \times M_P$ combined treatment, whereas the highest chlorophyll b was found in $I_3 \times M_S$ combined treatment. On the other hand, in the second experimental year, the highest chlorophyll contents were observed in $I_3 \times M_P$ treatment. In both the years, $I_0 \times M_0$ treatment showed the highest chlorophyll a:b ratio.

Table 2.14a: Effect of irrigation levels, variety and mulching on chlorophyll content of flag leaf of wheat in 2008-2009

Treatments	Chlorophyll content of flag leaf			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
a) Irrigation level				
I_0	1.685c	0.899c	2.582c	1.886
I_1	2.167d	1.179b	3.343d	1.837
I_2	2.487b	1.352a	3.838b	1.837
I_3	2.650a	1.406a	4.057a	1.880
LS	**	**	**	NS
b) Variety				
V_1	2.395a	1.253a	3.648a	1.911
V_2	2.099b	1.165b	3.263b	1.809
LS	**	**	**	NS
c) Mulching				
M_0	1.916b	1.020b	2.936b	1.892
M_w	2.323a	1.256a	3.577a	1.848
M_s	2.348a	1.276a	3.625a	1.837
M_p	2.401a	1.284a	3.683a	1.863
LS	**	**	**	NS
CV (%)	4.00	2.88	2.38	6.16

Table 2.14b: Effect of irrigation levels, variety and mulching on chlorophyll content of flag leaf of wheat in 2009-2010

Treatments	Chlorophyll content of flag leaf			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
a) Irrigation level				
I_0	1.761d	0.929c	2.690c	1.907
I_1	2.267c	1.224d	3.490d	1.852
I_2	2.597b	1.400b	3.997b	1.852
I_3	2.761a	1.519a	4.281a	1.835
LS	**	**	**	NS
b) Variety				
V_1	2.501a	1.329a	3.831a	1.899a
V_2	2.192b	1.207b	3.399b	1.825b
LS	**	**	**	**
c) Mulching				
M_0	2.001c	1.056c	3.058c	1.909a
M_w	2.432b	1.305b	3.737b	1.864b
M_s	2.454ab	1.322ab	3.777ab	1.854b
M_p	2.499a	1.389a	3.887a	1.820b
LS	**	**	**	**
CV (%)	3.20	9.94	5.52	4.47

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels: I_0 = no irrigation I_1 = 2 cm irrigation I_2 = 4 cm irrigation I_3 = 6 cm irrigation

Variety : V_1 = Prodip V_2 = Sufi

Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene

Table 2.15a: Interaction effect of irrigation levels and mulching on chlorophyll content of flag leaf of wheat in 2008-2009

Treatments	Chlorophyll content of flag leaf			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
I_0M_0	1.428g	0.727	2.152i	2.000
I_0M_w	1.758f	0.938	2.697h	1.867
I_0M_s	1.773f	0.960	2.733h	1.843
I_0M_p	1.780f	0.972	2.748gh	1.833
I_1M_0	1.862f	1.007	2.865g	1.853
I_1M_w	2.240d	1.218	3.455e	1.840
I_1M_s	2.275d	1.238	3.512e	1.835
I_1M_p	2.290d	1.253	3.542e	1.822
I_2M_0	2.132e	1.148	3.280f	1.853
I_2M_w	2.582c	1.402	3.982d	1.840
I_2M_s	2.605bc	1.420	4.027d	1.830
I_2M_p	2.628bc	1.438	4.063cd	1.825
I_3M_0	2.243de	1.200	3.447e	1.863
I_3M_w	2.712ab	1.465	4.177bc	1.845
I_3M_s	2.740a	1.487	4.228b	1.838
I_3M_p	2.905a	1.473	4.378a	1.973
LS	*	NS	**	NS
CV (%)	4.00	2.88	2.38	6.16

Table 2.15b: Interaction effect of irrigation levels and mulching on chlorophyll content of flag leaf of wheat in 2009-2010

Treatments	Chlorophyll content of flag leaf			
	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
I_0M_0	1.492i	0.750	2.240	2.025
I_0M_w	1.838h	0.973	2.810	1.885
I_0M_s	1.853gh	0.990	2.847	1.868
I_0M_p	1.860gh	1.003	2.865	1.852
I_1M_0	1.945g	1.040	2.985	1.867
I_1M_w	2.357e	1.270	3.627	1.855
I_1M_s	2.375e	1.285	3.660	1.850
I_1M_p	2.390e	1.300	3.690	1.837
I_2M_0	2.227f	1.188	3.415	1.872
I_2M_w	2.697d	1.450	4.148	1.857
I_2M_s	2.723d	1.472	4.193	1.843
I_2M_p	2.743cd	1.488	4.232	1.838
I_3M_0	2.342e	1.247	3.592	1.873
I_3M_w	2.837bc	1.525	4.362	1.860
I_3M_s	2.865b	1.542	4.408	1.855
I_3M_p	3.002a	1.763	4.763	1.753
LS	**	NS	NS	NS
CV (%)	3.20	9.94	5.52	4.47

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels: I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation

Variety : V_1 = Prodip V_2 = Sufi

Mulching : M_0 = no mulching M_w = water hyacinth M_S = rice straw M_P = black polythene

4.5 YIELD AND YIELD CONTRIBUTING CHARACTERS

Most of the yield and yield components such as plant height, the number of total tillers plant^{-1}, the number of effective tillers plant^{-1}, spike length, extrusion length, the number of fertile spikelets spike^{-1}, 1000-grain weight, grain yield, straw yield, biological yield and harvest index significantly varied due to different irrigation levels and mulching treatments in both the varieties and experimental years (Tables 2.16a and 2.16b).

4.5.1 Plant height

Plant height of both the varieties of wheat influenced by different irrigation levels and mulching treatments is presented in the Tables 2.16a and 2.16b for both the growing seasons. Irrigation levels had significant effect on plant height (Appendices XVa and XVb). It increased with increasing levels of irrigation. Treatment I_3 (6 cm of irrigation) produced significantly higher plant height followed by I_2 (4 cm of irrigation) and I_1 (2 cm of irrigation). The shortest plants were produced by I_0 (no irrigation) in both the years. Between the two varieties, Prodip produced the taller plants than Sufi. Amongst the mulching treatments, the tallest plants were produced by black polythene mulch (M_P) followed by rice straw mulch (M_S) and water hyacinth mulch (M_W). No mulching (M_0) produced the shortest plants.

The interaction effect between irrigation and mulching was also found to be significant. Amongst the different treatment combination, $I_3 \times Mp$ (6 cm irrigation × black polythene mulch) produced tallest plants followed by $I_3 \times Ms$ (06 cm irrigation × rice straw mulch) (Tables 2.17a and 2.17b).

4.5.2 Number of total tillers plant^{-1}

Tables 2.16a and 2.16b show that the number of total tillers plant^{-1} was significantly influenced by both irrigation levels and mulching treatment (Appendices XVa and XVb). The highest level of irrigation (I_3) produced the highest number of total tillers plant^{-1} followed by I_2 and I_1 levels of irrigation in both the years. The lowest number of total tillers plant^{-1} was produced with no irrigation (I_0).

Prodip produced the higher number of total tillers plant^{-1} than Sufi in both the experimental years (Table 16a and 2.16b). The lowest number of total tillers plant^{-1} was produced by no mulching (M_0) and the highest number of total tillers plant^{-1} was produced by black polythene mulch (M_P) followed by rice straw (M_S) and water hyacinth (M_W) mulches in every year.

The number of total tillers plant^{-1} was not significantly influenced by the interaction effect of irrigation and mulching. The highest level of irrigation (I_3) and use of black polythene mulch (M_P) combinedly produced the highest number of total tillers plant^{-1} in both the years followed by $I_3 \times Ms$ (Tables 2.17a and 2.17b).

4.5.3 Number of effective tillers plant^{-1}

A significance influence of irrigation and mulching treatment on the two experimental wheat varieties shown in the (Appendices XVa and XVb). It also illustrates that the number of effective tillers plant^{-1} was increased by increasing levels of irrigation. The highest number of total tillers plant^{-1} was produced by I_3 treatment followed by I_2 and I_1 treatments. No irrigation (I_0) produced the lowest number of effective plant^{-1} in both the seasons. Between the two varieties, Prodip (V_1) produced the higher number of effective tillers plant^{-1} than Sufi (V_2) in both the years.

Amongst the different mulching treatments, black polythene mulch (M_P) ranked the top to produce the highest number of effective tillers plant^{-1} followed by rice straw (M_S) and water hyacinth (M_W) mulches in both the years. No mulching produced the lowest number of effective tillers plant^{-1}.

A significant interaction was found between the different irrigation levels and mulching treatments in producing varied number of effective tillers plant^{-1} in both the years (Tables 2.17a and 2.17b). The highest number of effective tillers plant^{-1} was produced by the combined treatment of six centimetre irrigation and black polythene mulch ($I_3 \times M_P$) followed by $I_3 \times M_S$. $I_0 \times M_0$ treatment combination produced very much poor number of effective tillers plant^{-1}.

4.5.4 Number of non-effective tillers plant^{-1}

Number of non-effective tillers plant^{-1} was significantly influences by irrigation levels (Appendices XVa and XVb). Increased levels of irrigation decreased the number of non-effective tillers plant^{-1} (Tables 2.16a and 2.16b). The highest and the lowest number of non-effective tillers plant^{-1} was produced by I_0 and I_3 treatments.

Varieties also showed significant influence on the number of non-effective tillers plant^{-1}. Prodip produced the lower number of non-effective tillers plant^{-1} than Sufi (Tables 2.16a and 2.16b).

Mulching effects was found significant on the number of non-effective tillers plant^{-1}. M_P produced lower number of non-effective tillers plant^{-1}

than other mulching materials. The interaction effect of irrigation and mulching was non-significant (Tables 2.17a and 2.17b).

4.5.5 Spike length

Spike length varied significantly due to different levels of irrigation and mulching in both the wheat varieties and the years (Appendices XVa and XVb). Spike length was increased by increasing the levels of irrigation. I_3 produced the tallest spikes in both the varieties followed by I_2 and I_1. The shortest spikes were found to be produced by no irrigation (I_0) treatment in both the varieties and years. The taller spikes were in Prodip in both the years. A significant variation in spike length was also found amongst the mulching treatments. Black polythene mulch (M_P) was found to produce the highest spike length followed by rice straw (M_S) and water hyacinth (M_W) mulches. In both the years, the shortest spikes were produced by no mulching (M_0).

The influence of irrigation levels and mulching on the spike length is shown in the Table2.17a and 2.17b. The highest spike length was produced by the combined effect of $I_3 \times M_P$ followed by $I_2 \times M_S$ and $I_2 \times M_S$ in both the years. No irrigation and no mulching ($I_0 \times M_0$) produced the shortest spikes in both the years.

4.5.6 Extrusion length

The plants with higher irrigation levels had higher extrusion length than lower irrigation levels in two wheat varieties in both the years (Table 2.16a and 2.16b). The highest extrusion length was in I_3 treatment followed by I_2 and I_1 treatments in both the years. Extrusion length decreased with lower irrigation levels and no irrigation produced the shortest extrusion length in both the years. Sufi produced shorter extrusion length both the years than Prodip.

Mulching treatment also had significant effects on extrusion length (Appendices XVa and XVb). No mulching (M_0) was found to produce the shortest extrusion length followed by rice straw (M_S) and water hyacinth (M_W) mulches every year.

The combined effect of irrigation and mulching was also significant of the extrusion length of the wheat varieties. Treatment combination $I_3 \times M_P$ produced the longest and $I_0 \times M_0$ produced the shortest extrusion length in every experimental year (Tables 2.17a and 2.17b).

4.5.7 Number of spikelets spike^{-1}

The significant effect of the different irrigation levels on the number of spikelets spike^{-1} is shown in the Appendices XVa and XVb. The results indicate that the number of spikelets spike^{-1} increased with higher doses of irrigation. I_3 treatment produced the highest number of spikelets spike^{-1} followed by I_2 and I_1 in both the years. Conversely, no irrigation (I_0) gave the lowest number of spikelets spike^{-1}. Prodip, between the two wheat varieties produced the higher number of spikelets spike^{-1} in both the years. Tables 2.16a and 2.16b shows that amongst all the mulching treatments, black polythene mulch (M_P) produced the highest number of spikelets spike^{-1} in both the years followed by rice straw (M_S) and water hyacinth (M_W) mulches. The lowest number of spikelets spike^{-1} was produced from no mulch (M_0). The interaction of irrigation and mulching had significant effect on spikelets spike^{-1} (Tables 2.17a and 2.17b). The highest level of irrigation (I_3) and black polythene mulch (M_P)

combinedly produced the highest number of spikelets spike^{-1} followed by I_3×M_S and I_2×M_P treatments in both the years. The lowest number of spikelets spike^{-1} was produced with the combined treatment of I_0×M_0 in both the seasons.

4.5.8 Number of fertile spikelets spike^{-1}

A significant variation in the number of fertile spikelets spike^{-1} was observed with the variation of irrigation levels (Appendices XVa and XVb). It reveals from the table that the plants with six centimetres of irrigation (I_3) treatment had the highest number of fertile spikelets spike^{-1} followed by four centimetres of irrigation (I_2) and two centimetres of irrigation (I_1) treatments in both the years. No irrigation or control treatment (I_0) had the lowest number of fertile spikelets spike^{-1} in both the years.

Between the two wheat varieties, Prodip produced the higher number of fertile spikelets spike^{-1} than the other variety Sufi in both the growing seasons. The table also shows that the highest number of fertile spikelets spike^{-1} was produced by black polythene mulch (M_P) followed by rice straw (M_S) and water hyacinth (M_W) mulches in both the years. The interaction effects of irrigation levels and mulching exhibited a significant variation in producing the highest number of fertile spikelets spike^{-1} in both the years (Table 2.17a and 2.17b). I_3 with black polythene mulch produced the highest number of fertile spikelets spike^{-1} in both the years followed by I_3×Ms.

4.5.9 Number of sterile spikelets spike^{-1}

A significant difference of number of sterile spikelets spike^{-1} as influenced by different irrigation level was found in the present study

(Appendices XVa and XVb). Result shows higher irrigation levels decreases the number of sterile spikelets spike^{-1} (Table 2.16a and 2.16b). I_3 treatment produced the lowest number of sterile spikelets spike^{-1} compared to control treatment. The varietal differences influenced the number of sterile spikelets spike^{-1} only in the first year. Prodip showed higher number of sterile spikelets spike^{-1} in the first year but it was reversed by Sufi in the second year (Tables 2.16a and 2.16b). Mulching also had significant effect on the number of sterile spikelets spike^{-1}. Black polythene mulch (M_P) produced the lowest number of sterile spikelets spike^{-1} followed by rice straw (M_S) andwater hyacinth (M_W). Interaction effect of irrigation and mulching was only significant in the first year. $I_0 \times M_P$ and $I_0 \times M_W$ produced the highest number of sterile spikelets spike^{-1}in the first and in the second year respectively (Tables 2.17a and 2.17b).

4.5.10 1000-grain weight

The significant influence of irrigation levels and mulching treatments on the production of 1000-grain weight of the two experimental wheat varieties are shown in the Appendices XVa and XVb. It shows that 1000-grain weight increased with increasing the levels of irrigation in both the varieties and the years. I_3 produced the highest 1000-grain weight followed by I_2 and I_1 treatments. Between the experimental varieties, Prodip produced the higher weight of 1000-grain than Sufi. Amongst all the mulching treatments, the highest 1000-grain weight was produced by black polythene (M_P) followed by rice straw (M_S) and water hyacinth (M_W) mulches in both the years (Tables 2.16a and 2.16b). No mulch (M_0) produced the lowest 1000-grain weight in both the growing seasons. A significant interaction was also found between irrigation and mulching in producing 1000-grain weight. Tables 2.17a 2.17b, reveals $I_3 \times M_P$

produced the highest 1000-grain weight followed by $I_3 \times M_S$ and $I_2 \times M_P$ treatment. The combined control treatment ($I_0 \times M_0$) had the lowest 1000-grain weight in both the experimental years.

4.5.11 Grain yield (t ha^{-1})

The different levels of irrigation had a significant influence on the grain yield of the experimental wheat varieties in both the years (Appendices XVa and XVb). Tables 2.16a and 2.16b shows that the higher levels of irrigation resulted in higher grain yield. The highest amount of grain yield was produced by I_3 treatment followed by I_2 and I_1 treatments. No irrigation or control treatment produced the lowest amount of grain yield. In case of the two wheat varieties, Prodip produced more grain yield than Sufi. The highest amount of grain yield was produced by black polythene (M_P) followed by rice straw (M_S) and water hyacinth (M_W) (Tables 2.16a and 2.16b). No mulching treatment (M_0) had minimum amount of grain yield each year. The combined effect of irrigation and mulching also had significant variation of grain yield (Tables 2.17a and 2.17b). The combined treatment of six centimetres irrigation and black polythene mulch ($I_3 \times M_P$) showed the highest results in grain yield production in both the years followed by $I_3 \times M_S$. the lowest grain yield per hectare was produced by the combination of $I_0 \times M_0$.

4.5.12 Straw yield (t ha^{-1})

A significant variation in straw yield (t ha^{-1}) was observed with the variation of irrigation levels (Appendices XVa and XVb). From the Tables 2.16a and 2.16b, it was found that the highest straw yield was produced by the irrigation of four centimetres (I_2) followed by the irrigation of six centimetres (I_3). Conversely, no irrigation (I_0) had the lowest amount of straw yield. The production of straw yield (t ha^{-1}) was varied significantly. in both the growing seasons, black polythene mulch (M_P) was found to produce highest straw yield (t ha^{-1}) followed by rice straw mulch (M_W) and water hyacinth mulch (M_W). No mulching production the lowest amount of straw yield. A significant variation influenced by combined applications was also found in producing varied straw yield. Tables 2.17a and 2.17b shows that, in the first growing season, the combined application of four centimetre irrigation and rice straw mulch ($I_2 \times M_S$) had the highest straw yield and combined application of four centimetre irrigation and black polythene mulch ($I_2 \times M_P$) produced highest straw yield in the second year. In both the years, the combined application of no irrigation and no mulching ($I_0 \times M_0$) produced the lowest straw yield.

4.5.13 Biological yield (t ha^{-1})

The biological yield of the two experimental wheat varieties influenced by irrigation levels is presented in the Tables 2.16a and 2.16b. It was observed from the table that I_2 irrigation treatment had the highest biological yield (t ha^{-1}) followed by I_3 and I_1 irrigation treatments in both the years. No irrigation (I_0) produced the least amount of biological yield.

Between the two varieties, Prodip produced the higher biological yield than Sufi every year. Different mulching treatments also showed a significant variation in the production of biological yield (Appendices XVa and XVb). Rice straw mulch (M_S) produced the highest amount of biological yield of wheat per hectare in both the years followed by black polythene (M_P) and water hyacinth (M_W) mulches. No mulching (M_0) had the lowest amount of biological yield.

A significant combined effect of irrigation and mulching was also found in biological yield production. The highest biological yield per hectare was produced by the combined effect of four centimetre irrigation and black polythene mulch ($I_2 \times M_P$) followed by the combined effect of four centimetre irrigation and rice straw mulch ($I_2 \times M_S$) in both the years. The combined effect of no irrigation and no mulching ($I_0 \times M_0$) produced the lowest biological yield in both the years.

4.5.14 Harvest Index

Harvest index varied significantly due to different levels of irrigation and mulching in both the wheat varieties and the years (Appendices XVa and XVb). Harvest index was increased by increasing the levels of irrigation. I_3 produced the highest harvest index in both the varieties followed by I_2 and I_1. The lowest harvest index was found to be produced by no irrigation (I_0) treatment in both the varieties and years. The highest harvest index was in Prodip in every year. A significant variation in harvest index was also found amongst the mulching treatments. Black polythene mulch (M_P) was found to produce the highest harvest index followed by rice straw (M_S) and water hyacinth (M_W) mulches. In both the years, the lowest harvest index was produced by no mulching (M_0).

The influence of irrigation levels and mulching on the spike length is shown in the Table2.17a and 2.17b. The highest spike length was produced by the combined effect of $I_3 \times M_P$ followed by $I_2 \times M_S$ and $I_2 \times M_S$ in both the years. No irrigation and no mulching ($I_0 \times M_0$) produced the shortest spikes in both the years.

Table 2.16a: Effect of irrigation levels, variety and mulching on yield and yield components of wheat in 2008-2009

Treatments	Plant height (cm)	No. of total tillers plant^{-1}	No. of effective tillers plant^{-1}	No. of non-effective tillers plant^{-1}	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike^{-1}	Number of fertile spikelets spike^{-1}	Number of sterile spikelets spike^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
a) Irrigation levels														
I_0	58.99d	3.64c	2.46d	1.18a	17.10d	18.82d	12.823d	8.832d	3.991b	35.57d	2.77d	5.82c	8.59c	32.25d
I_1	72.46c	4.34d	3.12c	1.22a	20.79c	22.81c	15.503c	10.516c	4.988a	43.85c	3.42c	6.74b	10.16b	33.54c
I_2	84.40b	4.74b	3.75b	0.99b	24.04b	26.85b	17.862b	12.894b	4.969a	51.07b	4.02b	7.49a	11.51a	34.80b
I_3	92.43a	5.03a	4.12a	0.91b	26.50a	29.52a	19.625a	14.740a	4.885a	56.08a	4.43a	6.90b	11.33a	38.93a
LS	**	**	**	**	**	**	**	**	**	**	**	**	**	**
b) Variety														
V_1	85.68a	4.59a	3.56a	1.03b	24.48a	27.07a	18.20a	12.64a	5.57a	51.30a	3.78a	6.70b	10.47a	35.69a
V_2	68.46b	4.29b	3.16b	1.13a	19.73b	21.94b	14.70b	10.85b	3.85b	41.98b	3.54b	6.78a	10.32b	34.07b
LS	**	**	**	*	**	**	**	**	**	**	**	**	**	**
c) Mulching														
M_0	63.36d	3.73c	2.46d	1.27a	17.77d	20.09d	13.510d	6.179d	7.330a	37.84d	2.97d	6.03c	9.01d	32.94d
M_w	75.56c	4.26d	3.16c	1.10b	21.80c	24.08c	16.133c	11.763c	4.370b	45.77c	3.50c	6.67b	10.17c	34.15c
M_s	81.25b	4.71b	3.71b	1.00bc	23.74b	25.96b	17.426b	13.630b	3.797c	49.34b	3.89b	7.10a	10.99b	35.27b
M_p	88.12a	5.04a	4.11a	0.93c	25.12a	27.88a	18.742a	15.410a	3.335d	53.63a	4.27a	7.15a	11.42a	37.15a
LS	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	2.52	4.92	2.89	15.82	3.12	2.26	2.73	3.96	11.32	2.99	4.05	5.43	4.49	2.61

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene
LS = Level of Significance CV = Coefficient of Variation

Table 2.16b: Effect of irrigation levels, variety and mulching on yield and yield components of wheat in 2009-2010

Treatments	Plant height (cm)	No. of total tillers plant^{-1}	No. of effective tillers plant^{-1}	No. of non-effective tillers plant^{-1}	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike^{-1}	Number of fertile spikelets spike^{-1}	Number of sterile spikelets spike^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
a) Irrigation levels														
I_0	65.86d	3.90d	2.58d	1.33ab	17.65d	19.64d	13.18d	10.61d	2.57a	36.95d	2.60d	5.77d	8.36d	31.00d
I_1	81.35c	4.70c	3.31c	1.39a	21.51c	23.94c	15.89c	13.72c	2.17d	45.39c	3.21c	6.54c	9.75c	32.79c
I_2	94.73b	5.14b	3.97b	1.16bc	24.87b	28.17b	18.34b	16.54b	1.80c	52.85b	3.74b	7.42a	11.16a	33.35b
I_3	103.31a	5.42a	4.34a	1.08c	27.42a	31.14a	20.07a	18.37a	1.70c	57.90a	4.11a	6.80b	10.91b	37.41a
LS	**	**	**	**	**	**	**	**	**	**	**	**	**	**
b) Variety														
V_1	95.95a	4.95a	3.77a	1.19b	25.33a	28.49a	18.68a	16.66a	2.03	53.02a	3.80a	7.16a	10.96a	34.39a
V_2	76.67b	4.63b	3.34b	1.29a	20.40b	22.95b	15.06b	12.96b	2.09	43.52b	3.03b	6.11b	9.13b	32.88b
LS	**	**	**	*	**	**	**	**	NS	**	**	**	**	**
c) Mulching														
M_0	70.82d	4.03d	2.58d	1.45a	18.35d	20.97d	13.83d	11.48d	2.35a	39.69d	2.80d	5.88c	8.68d	31.98d
M_w	84.50c	4.60c	3.35c	1.25b	22.56c	25.27c	16.55c	14.45c	2.10ab	46.98c	3.34c	6.65b	9.99c	33.17c
M_s	90.71b	5.09b	3.93b	1.16b	24.57b	27.24b	17.86b	15.93b	1.93b	51.04b	3.58b	6.91a	10.50b	33.88b
M_p	99.22a	5.44a	4.34a	1.10b	25.99a	29.41a	19.23a	17.37a	1.86b	55.38a	3.95a	7.07a	11.02a	35.52a
LS	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	2.65	4.79	2.14	18.10	3.53	4.01	3.03	1.62	20.61	2.06	3.98	3.42	3.19	1.50

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation
Variety : V_1 = Prodip V_2 = Sufi
Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene

LS = Level of Significance   NS = Non-significant   CV = Coefficient of Variation

Table 2.17a: Interaction effect of irrigation levels and mulching on yield and yield components of wheat in 2008-2009

Treat-ments	Plant height (cm)	Number of total tillers plant^{-1}	Number of effective tillers plant^{-1}	Number of non-effective tillers plant^{-1}	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike^{-1}	Number of fertile spikelets spike^{-1}	Number of sterile spikelets spike^{-1}	1000 -grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
I_0M_0	47.53j	2.87	1.52j	1.34	13.11k	14.93i	10.24i	3.88j	6.36c	27.48i	2.15i	4.76i	6.91	31.58i
I_0M_w	58.25i	3.56	2.27i	1.30	17.09j	18.68h	12.71h	8.79h	3.93defg	35.36h	2.68h	5.80h	8.48	31.62i
I_0M_s	62.65h	3.93	2.85h	1.07	18.60i	20.14g	13.71g	10.56f	3.15gh	38.12g	2.99g	6.19fhg	9.18	32.56hi
I_0M_p	67.51g	4.19	3.20g	0.99	19.59hi	21.55f	14.63f	12.10e	2.53h	41.32f	3.25f	6.53efg	9.77	33.23fgh
I_1M_0	60.01hi	3.72	2.28i	1.44	16.92j	18.87h	12.80h	4.05j	8.75a	36.01gh	2.82h	5.98gh	8.80	32.03hi
I_1M_w	71.09f	4.17	2.92h	1.24	20.47gh	22.39f	15.15f	10.73f	4.42d	42.93f	3.27f	6.61def	9.87	33.05gh
I_1M_s	76.44e	4.60	3.45f	1.15	22.29f	24.14e	16.42e	12.86d	3.56efg	46.29e	3.63e	7.01cde	10.64	34.16defg
I_1M_p	82.31d	4.89	3.84d	1.06	23.48e	25.85d	17.65d	14.43c	3.22fgh	50.17d	3.95d	7.38bc	11.33	34.91de
I_2M_0	69.89fg	4.06	2.84h	1.22	19.56hi	22.21f	14.82f	7.07i	7.75b	41.95f	3.28f	6.77de	10.05	32.63hi
I_2M_w	82.81d	4.54	3.58e	0.97	23.67e	26.35d	17.53d	12.88d	4.65d	50.00d	3.80de	7.34bc	11.14	34.12efg
I_2M_s	89.04c	5.03	4.10c	0.93	25.77d	28.41c	18.92c	14.94c	3.98df	53.90c	4.23c	8.12a	12.35	34.44def
I_2M_p	95.89b	5.33	4.48b	0.85	27.14c	30.42d	20.17b	16.69b	3.49efg	58.43b	4.77b	7.74ab	12.51	38.01c
I_3M_0	76.02e	4.27	3.19g	1.08	21.46fg	24.36e	16.17e	9.72g	6.46c	45.92e	3.65e	6.62def	10.27	35.54d
I_3M_w	90.09c	4.79	3.89d	0.90	25.98d	28.89c	19.14c	14.66c	4.48d	54.78c	4.23c	6.96cde	11.19	37.80c
I_3M_s	96.86b	5.30	4.45b	0.85	28.29b	31.15b	20.66b	16.16b	4.50d	59.03b	4.71b	7.09cd	11.80	39.93b
I_3M_p	106.75a	5.76	4.94a	0.82	30.28a	33.70a	22.53a	18.43a	4.10de	64.60a	5.12a	6.95cde	12.07	42.45a
LS	**	NS	**	NS	**	**	**	**	**	**	*	**	NS	**
CV	2.52	4.92	2.89	15.82	3.12	2.26	2.73	3.96	11.32	2.99	4.05	5.43	4.49	2.61

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation

Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

Table 2.17b: Interaction effect of irrigation levels and mulching on yield and yield components of wheat in 2009-2010

Treat-ments	Plant height (cm)	Number of total tillers plant^{-1}	Number of effective tillers plant^{-1}	Number of non-effective tillers plant^{-1}	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike^{-1}	Number of fertile spikelets spike^{-1}	Number of sterile spikelets spike^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
I_0M_0	51.97i	3.08	1.51j	1.57	13.45k	15.19i	10.40i	7.78k	2.63	30.65k	2.05h	4.70h	6.76i	30.30i
I_0M_w	65.19h	3.82	2.40i	1.43	17.66j	19.61h	13.10h	10.40j	2.70	35.10j	2.58g	5.76g	8.33h	30.81i
I_0M_s	69.93g	4.21	3.02h	1.20	19.24i	21.12g	14.13g	11.51i	2.62	39.47h	2.76g	6.30f	9.06g	30.55i
I_0M_p	76.37f	4.50	3.39g	1.11	20.26hi	22.63f	15.07f	12.74h	2.34	42.60g	3.01f	6.29f	9.30fg	32.33fgh
I_1M_0	67.39gh	4.03	2.42i	1.60	17.50j	19.81h	13.14h	10.53j	2.61	37.28i	2.66g	5.73g	8.39h	31.67h
I_1M_w	79.47f	4.50	3.10h	1.41	21.19gh	23.50f	15.55f	13.31g	2.23	44.46f	3.14f	6.46f	9.60ef	32.60fg
I_1M_s	85.39e	4.98	3.65f	1.33	23.07f	25.32e	16.76e	14.77f	1.99	47.91e	3.37e	6.85de	10.22d	32.92f
I_1M_p	93.14d	5.29	4.06d	1.24	24.30e	27.12d	18.10d	16.26e	1.85	51.90d	3.67d	7.12cd	10.79c	33.97de
I_2M_0	78.50f	4.40	3.01h	1.39	20.24hi	23.30f	15.22f	13.06gh	2.16	43.38fg	3.10f	6.60ef	9.70e	31.85gh
I_2M_w	92.61d	4.92	3.79e	1.14	24.49e	27.65d	18.01d	16.17e	1.84	51.76d	3.66d	7.40bc	11.05c	33.01f
I_2M_s	99.39c	5.45	4.34c	1.11	26.68d	29.82c	19.41c	17.81d	1.61	55.78c	3.92c	7.64b	11.56b	33.84e
I_2M_p	108.42b	5.77	4.75b	1.02	28.09bc	31.92b	20.72b	19.15c	1.57	60.50b	4.28b	8.05a	12.33a	34.71d
I_3M_0	85.41e	4.61	3.38g	1.23	22.22fg	25.57e	16.56e	14.57f	1.99	47.46e	3.37e	6.49f	9.86de	34.12de
I_3M_w	100.72c	5.16	4.12d	1.04	26.88cd	30.32c	19.57c	17.94d	1.64	56.59c	3.98c	6.98d	10.96c	36.25c
I_3M_s	108.15b	5.72	4.72b	1.00	29.27b	32.70b	21.13b	19.62b	1.51	61.01b	4.27b	6.87de	11.14c	38.20b
I_3M_p	118.96a	6.20	5.16a	1.04	31.32a	35.98a	23.02a	21.35a	1.68	66.52a	4.82a	6.84de	11.66b	41.08a
LS	**	NS	**	NS	*	*	*	**	NS	**	**	**	*	**
CV	2.65	4.79	2.14	18.10	3.53	4.01	3.03	1.62	20.61	2.06	3.98	3.42	3.19	1.50

In a column, values followed by a common letter are not significantly different at 5% level by DMRT

Irrigation levels : I_0 = no irrigation I_1 = 2 cm of irrigation I_2 = 4 cm of irrigation I_3 = 6 cm of irrigation

Mulching : M_0 = no mulching M_w = water hyacinth M_s = rice straw M_p = black polythene

LS = Level of Significance NS = Non-significant CV = Coefficient of Variation

CHAPTER FIVE

Discussion

There are many environmental factors that control the growth, development and yield of wheat. The growth and yield of crops are often reduced by soil moisture stress. Proper irrigation can maintain optimum soil moisture that encourages the growth and development and ultimately reflects to the yield. The knowledge of irrigation requirement of wheat and the role of irrigation given at different frequencies, amount and growth stages is essential for getting higher crop production. Mulching is another practice that can utilize maximum irrigation water by reducing evapotranspiration. The results obtained in this study on different irrigation levels and mulching treatments on two wheat varieties are discussed below.

Total dry matter (TDM) production is the integration of crop growth rate over the entire growth period. TDM production of a crop depends on the size of leaves or its activities as well as the length of its growth period, during which photosynthesis continues (Watson, 1958). Tanaka (1983) expressed TDM as the product of the average crop growth rate (CGR) and growth duration. TDM production and distribution patterns are the most important factors for crop yield. Chauhan and Singh (1977) reported that dry matter increases in leaves up to the flowering stage and in stem up to hard dough stage. Later on, the dry matter of leaves and stem gradually decreases. Vergara, Lilis and Tanaka (1964) concluded that longer growth period produces higher TDM. TDM of a plant gradually increases with time. The rate of increase was initially slow, and then it was accelerated and later gradually decreased when crops were approaching to their maturity. The results of the present study revealed that TDM was higher in the irrigated plants than in the rain-fed plants in both the years and the varieties. I_3 treatment had the highest TDM and I_0 had the lowest TDM that supported by previous studies such as Simane, Peacock and Struik (1993), Sarker *et al.* (1996), Sarker and Paul (1997), Nahar and Paul (1998), Rahman *et al.* (2001), Shen *et al.* (2001), Haider (2002) and Rahman (2004) in wheat, Rashid *et al.* (2007) in barley, Krogman and Hobbs (1975) and Clarke and Simpson (1978) in rape, and Khan and Agarwal (1985), Mandal *et al.* (1986), Mondal and Paul (1992) and Begum and Paul (1993) in mustard. The cause rapid increase of TDM at the later stages was possibly due to the development of a considerable number of late tillers. Similar result was reported by Talukder (1987) in wheat. Amongst the two varieties, Prodip always had higher TDM than Sufi in all the growing stages. The production of TDM influenced by different mulching treatments had an increasing tendency from the early stage throughout the growing period with advancement of time. In the first year, mulching treatment did not have any significant effect on TDM but in the second year, black polythene significantly produced the highest TDM followed by rice straw and water hyacinth mulches in all the growing stages (Tables 2.1a and 2.1b). No mulch produced the lowest amount of TDM throughout the growing stages. Aujla and Cheema (1983) and Mondal (2003) reported the similar results. Gajendra ang Singh (1985) stated that the application of straw mulch increased the dry matter at all growth stages significantly. More conservation of soil moisture and its greater availability might have increased the dry matter of crop grown on mulching treatment (Agarwal and De, 1977).

Leaf area index (LAI), the ratio of total leaf area subtended by unit land area, is a measurement of photosynthesis surface. It is evident that the maximum value of LAI in wheat ranges from 1.5 to 4.0 (Watson, 1947). Leaf area reaches its maximum at about the time when the shoots have attained half of their final height. The increase of LAI occurred due to the increase of the leaf emergence and expansion rates in the irrigated plants (Tables 2.2a and 2.2b). As observed by Yang *et al.* (1990), starting from the lower value, LAI reached a certain peak and then declined with age. The value of LAI in the irrigated plants was greater than the control at all the growing stages. Similar results were reported in wheat by Leverton (1990), Nahar and Paul (1998) and Rahman (2004), in barley by Kirby (1969) and Rashid *et al.* (2007), and in sorghum by Constable & Hearn (1978). The highest LAI was produced by the highest irrigation treatment (I_3). The increase in LAI occurred due to increase in leaf expansion in irrigated plants. Increased soil moisture resulted in increased turgor pressure in the cells and turgor force played a part in the process of leaf expansion. With an increase in the level of irrigation, uptake of nutrients was more; hence more expansion of leaves took place (Mondal *et al.*, 1986). Soil moisture increased relative leaf water content (RLWC) that expanded cells and ultimately leaf area was increased. In the present study, different mulching treatments had significant effects on LAI in every growing stage in both the experimental years except 20 and 50 DAS in the first year. It increased up to 70 and 60 DAS in the first and second year, respectively and then declined till the final harvest. Amongst the different mulching treatments, black polythene produced the highest value of LAI followed by rice straw and water hyacinth. No mulch produced the lowest value of LAI in all the growing stages. This might be due to higher conservation of soil moisture by black polythene resulted in a higher value of LAI. It was also observed that increase in soil moisture availability promoted leaf area and significantly moisture stress had reduced LAI values compared to other mulch materials. Similar result in wheat was also reported by Choudhury and Kumar (1980).

Crop growth rate (CGR) is the most meaningful growth function since it represents the net results of photosynthesis, respiration and canopy area interaction. CGR is also representative of the most common agronomic measurement such as yield of dry matter per unit land area according to Williams *et al.* (1965). In the present research, CGR was higher in the irrigated plants compared to control. The highest CGR was in plants grown under the highest irrigation level (I_3) except at 50-60 DAS in the second year. Higher CGR in the irrigated plants was due to higher dry matter production owing to higher LAI (Watson, 1947). CGR increased rapidly at the early growth stage and reached to the peak at 60-70 DAS in both the years and varieties, and thereafter, it declined (Fig.5a). Similar trend of effect of irrigation was also reported by Sarker *et al.* (1996), Sarker and Paul (1998), Nahar and Paul (1998) and Rahman (2004) in wheat, Rabindranath and Shivraj (1983) in sorghum, Clarke and Simpson (1978) in rape, and Mondal and Paul (1992) in mustard. Between the two varieties, the influence of mulching on LAI was not significant in the first year. Conversely, in the second year, the influence of mulching on LAI was significant in all the growing stages except 90-100 DAS. Prodip always showed higher value of CGR than Sufi. A significant effect of different mulching treatments on CGR of wheat was found only in the second year except 90 DAS. From an initial stage, the highest CGR was observed at 60 and 70 DAS and then it declined till the final harvest. The black polythene manifested a higher CGR might be due to comparatively a higher soil moisture conservation. No mulch produced the lowest CGR on all the growth stages. This result was supported by Mondal (2003). The decline in the CGR value at the later stages of growth might be due to shading of lower leaves and thereby photosynthesis decreased gradually, consequently the CGR also decreased.

Irrespective of irrigation and mulching treatments relative growth rate (RGR) declined with increasing plant age and TDM (Fig.6a). Similar results were reported for RGR in sugar beet, potato and barley (Thorne, 1960) and in wheat (Sarker and Paul, 1998). It had been suggested that the declining tendency of RGR could be due to self-shading of lower leaves by upper leaves (Thorne, 1961). The reason for higher RGR values at the earlier stages of growth is possible to have the juvenility of the plants and less effects on accumulation of dry matter. In most of the cases, RGR did not follow any specific trend. The pattern of RGR indicated that RGR declined gradually with time having small positive values at the later stages of growth. Higher RGR was noticed at the early stage of growth in both the varieties and years. Similar results were reported by El-Shaer *et al.* (1979), Saha and Paul (1995), Sarker and Paul (1998) and Rahman (2004) in wheat. In addition, RGR of both cultivars decreased steadily with increasing age and plant dry weight. Similar observations were reported by Pandey, Saxena and Singh (1978), in mustard by Mondal and Paul (1992), in rape by Kundu (1992), and in wheat by Haque (1993), Rahman (1993), Tarique (2003) and Rahman (2004). Mulching effects on RGR was not significant in both the experimental year.

Gain in dry matter per unit assimilatory area per unit time is known as net assimilation rate (NAR). It is an important index of photosynthetic efficiency of a cultivar (Haloi and Baldev, 1986). It was established that

NAR became higher during early vegetative phase and declined rapidly as growth progressed (Koller *et al.*, 1970; Haloi and Baldev, 1986). This might be due to mutual leaf-shading and increased the number of old leaves with lost photosynthetic efficiency (Pandey *et al*., 1978). In the present study, NAR fluctuated due to irrigation in both the growing seasons. Sometimes it was higher in the non-irrigated plants and vice-versa. Decreases in NAR due to irrigation treatments was noticed in wheat by Saha and Paul (1995), Nahar and Paul (1998), Sarker and Paul (1998). Conversely, higher or fluctuating NAR due to different irrigation levels was found in barley by Mollah (2007), in wheat by Haque (1993) and Rahman (1993), and in beans by El-Nadi (1969) and Nerkar *et al.* (1981). With some exceptions variety was almost significant in both the years but in the first year Prodip and in the second year Sufi produced higher NAR. NAR was not significantly influenced by different mulching treatments with few exceptions in the second experimental year.

Starting from a higher value, leaf area ratio (LAR) declined steadily with increasing plant age in every experimental year and in both the varieties (Fig. 8a). It might be due to abscission of matured and older leaves at the later growing stages. Similar results were in sugar beet, potato and barley by Thorne (1960), in black gram by Pandey *et al.* (1978), in rape by Murtaza and Paul (1986), and in wheat by Haque (1993), Rahman (1993) and Saha and Paul (1995). In this study, higher LAR was observed in the rain-fed wheat plants only at the first harvest (20 DAS) which is similar to the findings of Nahar and Paul (1998) but from the next harvest to maturity, it became reversed and fluctuating the result was partially supported by Kirby (1969) in barley; Nerkar *et al.* (1981) in *Vicia faba* by Mondaland and Paul (1994) in mustard; and by Haider *et al.* (2007) in wheat. Variety was almost significant in both the experimental year with few exceptions in the second year. Sufi showed higher LAR in all the growth stages except 60-70 DAS in the second year. This results might be due to different genetic traits of the varieties. Mulching did not follow any pattern and was not significant LAR of wheat in the present study.

In the present study, relative leaf growth rate (RLGR) values were found to decrease with the increasing plant age (Fig.9a). Similar findings were observed by Rahman (1993), Saha and Paul (1995), Sarker and Paul (1998) and Sarker *et al.* (1999) in wheat. The cause of declination of RLGR at the later stage was due to abscission of older leaves. It was also observed that high temperature at the later stage of growth accelerated the abscission of older leaves. The abscission of older leaves resulted in the decline of RLGR at the later stages of growth (Pandey *et al.*, 1978). RLGR values were found to be increased with increasing level of irrigation in both the varieties and years with some exceptions. Comparatively higher RLGR values were found in the irrigated plants than in the non-irrigated plants (Saha and Paul, 1995; Sarker *et al.*, 1996; Sarker and Paul, 1998). Mondal and Paul (1992) and Khan and Paul (1993) observed higher RLGR in well-watered condition in mustard. No clear pattern of development was found by Haider *et al.* (2007) for RLGR in both the irrigated and rain-fed wheat plants. Effect of variety and mulching was almost non-significant with a very few exceptions and no fixed trend of RGRL values were found in the present study.

Both the wheat varieties in the present study had higher specific leaf area (SLA) at first harvest (20 DAS) but it was lower in the second harvest (30 DAS) and then slightly increased at third harvest (40 DAS) and finally declined again throughout the growing period till the final harvest (Fig.10a and 10b). This declining tendency of SLA with increasing plant age was noticed in rape and turnip by Paul (1980), in jute by Saha (1983), in pearl millet by Chanda *et al.* (1987), and in wheat by Rahman (1993), Saha and Paul (1995) and Sarker and Paul (1998). The pattern of SLA values was fluctuating in the first experimental year but, in the second year, the highest level of irrigation produced higher SLA values almost in every stage of growth. This result is similar to the findings of Sarker and Paul (1998) and Rahman (2004) in wheat. No clear pattern of SLA was found as affected by variety and mulching in the present research.

The leaf weight ratio (LWR) showed a downward tendency with plant age in both the varieties and years. The decrease of LWR was caused by increasing TDM and decreasing LAI at later stages of growth. Saha and Paul (1995) studied LWR in wheat and reported that the sharp declining trend in LWR at the later stages of growth might be due to sharp increase of TDM. This result was also supported by Thorne (1960) in barley, and Nahar and Paul (1998) in wheat. LWR pattern was fluctuating in both the experimental year. Kundu and Paul (1998) reported that LWR was greater in the non-irrigated plants at most of the stages in rape. Besides, Haider *et al.* (2007) observed higher values of LWR in the rain-fed wheat (var. Akbar) while Sarker and Paul (1998) found higher LWR in the irrigated condition in wheat. No clear varietal and mulching effect was found in the present study.

In the present study, the irrigated plants had significantly higher moisture retention capacity than non-irrigated plants. Similar results were observed in wheat (Sarker *et al.*, 1996; Sarker and Paul, 1997). Both the varieties had the lowest moisture retention capacity in the rain-fed plants. Sarker *et al.*, 1999) also found higher moisture retention capacity in Opata under irrigated condition. Similar results were also observed by Haider (2002) in different wheat varieties grown under various soil moisture regimes. The ability of a leaf to retain higher moisture may be due to its higher sensitivity of stomatal opening with higher leaf area. The results show higher moisture retention capacity was found at early hours of the day but it decreased gradually at the later part of the day (Tables 2.10a and 2.10b). This might be due to folding of the leaves owing to increased dryness and also because of higher evapotranspiration rates. Variety and mulching also had significant effect on MRC on wheat flag leaf. Prodip always had higher MRC than in Sufi. This might be due to their different genetic makeup. M_P showed higher MRC followed by M_S and M_W over control treatment.

Relative leaf water content (RLWC) is the relationship between the actual and fully turgid water contents of leaf tissues (Baker, 1984) and it represents the severity of dehydration of leaf when it experiences water stress and is closely associated with the development and physiological activities (Morgan, 1971). The highest RLWC was observed at 8:00 AM in flag leaf of wheat and then gradually decreased till mid-day and again recovered later in both the varieties and the years. Some previous studies also had the same observations (Islam *et al.*, 1988; Begum and Paul, 1993; Rahman, 1993; Rahman and Paul, 1998; Sarker *et al.*, 1999; Haider, 2002; Paul *et al.*, 2002). It is understood that there is a negative relationship between RLWC, and temperature and light intensity. The declination of RLWC at mid-day is due to higher evapotranspiration owing to increased temperature and light intensity. The irrigated plants of both varieties at different times of the day always had higher RLWC than the rain-fed plants in every experimental year. The highest RLWC of wheat flag leaf was recorded in I_3 treatment and the lowest value was found in I_0 (Tables 2.12a and 2.12b). This result was supported by the findings of Rajagopal *et al.* (1977), Nayak *et al.* (1983), Rahman (1993, 2004), Sairam (1993), Haider (1997), Sarker *et al.* (1999), Paul *et al.* (2002), and Haider and Paul (2003) in wheat. Chandrasekar *et al.* (2000) reported that rain-fed condition caused a decline in RLWC in both the tetraploid and the hexaploid wheat. Chaves (1991) suggested that RLWC as an appropriate indicator of plant water status and drought tolerant varieties which can be identified with greater certainty by a high RLWC following a period of drought. Increased irrigation level can produce higher RLWC that also found by Begum and Paul (1993) in mustard, Kundu and Paul (1996) in rape seed, Rahman and Paul (1998) and Haider and Paul (2003) in wheat. Kramer (1969) expressed that higher RLWC was associated with higher TDM rates of the irrigated plants because of the cell turgidity in relation to the opening and closing of stomata, expansion of leaves and flowers, and the movement of water nutrients to various parts of the plants. Agenbag *et al.* (1995) stated that rain-fed condition decreased RLWC as well as increased leaf diffusive resistance. RLWC of wheat flag leaf was significantly affected by varieties and different mulching treatments. Prodip had higher RLWC than Sufi in both the years. M_P always showed the highest value of RLWC followed by M_S and M_W over M_0. Kumar *et al*. (2009) stated that, RLWC was improved by combination treatment of deep tillage, farm yard manure and mulch.

In the photosynthesis process, chlorophyll a and chlorophyll b are the most important pigments in plants. Increased chlorophyll contents absorbed higher quantity of light and hence increased photosynthesis. Several workers have reported that the rate of photosynthesis in leaves is positively associated with chlorophyll content (Freeland, 1948; Rabinowitch, 1951; Muramoto *et al.*, 1865; Kariya and Tsunoda, 1971) but Hesketh (1963) and Kumari and Sinha (1972) failed to find out any relationship between chlorophyll and the rates of photosynthesis. In the present study, significant effect of different irrigation levels and mulching treatments on chlorophyll a, chlorophyll b and total chlorophyll of two wheat varieties was noticed in both the growing seasons (Tables 2.14a and 2.14b) but chlorophyll a: b ratio was not significantly affected by varieties and mulching treatments in the second year. The irrigated plants had higher chlorophyll a, chlorophyll b and total chlorophyll than the rain-fed plants of the flag leaf of wheat. I_3 treatment had the highest chlorophyll a, chlorophyll b and total chlorophyll content than control (I_0). Similar results were reported by Chetal *et al.* (1982), Ashraf *et al.* (1994), Sarker *et al.* (1999), Chandrasekar *et al.* (2000), Nyachiro *et al.* (2001), Haider (2002), Paul *et al.* (2002) and Mollah (2007). Silaeva and Tkachuk (1982) reported that chloroplasts, photosynthetic membranes and the amount of thylakoid grana decreased with intensification of soil water stress but the chlorophyll a:b ratio was non-significant due to variation of irrigation frequency. This result was agreement with Ashraf *et al.* (2001) in pearl millet, where they observed no significant effect on chlorophyll a:b ratio but a slight increase was observed under water deficit condition. Paul *et al.* (2002) noticed significantly higher chlorophyll a:b ratio in the irrigated plants of wheat. Ashraf *et al.* (1994) noticed that chlorophyll a:b ratio increased under rain-fed conditions and the effect was more pronounced in the drought susceptible varieties. Abdrakhimov *et al.* (1996) reported that total chlorophyll and chlorophyll a:b ratio in wheat leaves were not affected by water shortage. In the present study, varietal and mulching had individual significant effect on chlorophyll a, chlorophyll b and total chlorophyll. Prodip and M_P individually showed higher chlorophyll a, chlorophyll b and total chlorophyll in both the years.

Crop yield and yield components may be influenced by many morphological, physiological and environmental characters. In the present study, yield and yield components were significantly affected by different irrigation levels and mulching.

Plant height is an important morphological character directly linked with the productive potential of plants in terms of grain yield. The highest plant height was observed in I_3 treatment and the lowest value was found with no irrigation (I_0) or control (Tables 2.16a and 2.16b). Plant height increased with increasing levels of irrigation. Similar result was reported in wheat by El Nadi (1969), Patel *et al.* (1971), Anonymous (1975), Islam (1997), Jana and Mitra (1995), Sarker and Paul (1997), Pandit *et al.* (2001), Rahman *et al.* (2001), Haider (2002) and Rahman (2004), and, in barley, Singh and Kaur (2001) and Mollah (2007). Between the varieties, the higher plant height was found in Prodip compared to Sufi which was partially similar to the results recorded by Soyeb (2011).

Amongst the mulching treatments, the tallest plant was recorded from black polythene mulch at harvest (Tables 2.16a and 2.16b) followed by rice straw and water hyacinth. No mulching treatment produced the shortest plant in both the years. This might be due to soil moisture content and temperature differences amongst the mulching treatments. Black polythene mulch conserved more soil moisture than the control. The result is partially similar to that reported by Misra (1996), who found that soil mulching increased the availability of conserved moisture in the soil profile and significantly enhanced plant height. This result is also supported by Mondal (2003). The interaction effect of irrigation and mulching is also significant in both the years (Tables 2.17a and 2.17b).

The significant influence of irrigation, variety and mulching was noticed on the number of total tillers plant^{-1} in both the years (Tables 2.16a and 2.16b). The number of total tillers plant^{-1} was higher in the irrigated plants than in the control. Similar results were also observed by previous studies such as Hassan *et al.* (1987), Leverton (1990), Roy and Gallagher (1991), Haque (1993) and Rahman (1993) in wheat, and Krishnayyan and Murty (1991) in rice. In the present study, I_3 treatment had the highest number of total tillers plant^{-1} in every experimental year. This result is also corroborated with Patel *et al.* (1971), Rahman *et al.* (2001) and Rahman (2004) in wheat.

Higher number of total tillers plant^{-1} was found in the variety Prodip which is partially supported by the result observed by Soyeb (2011). Sufi produced the lower number of total tillers plant^{-1} (Tables 2.16a and 2.16b).

Black polythene and no mulch produced the highest and the lowest numbers of total tillers plant^{-1}, respectively (Tables 2.16a and 2.16b). Mulching might have reduced the fluctuation of soil temperature and increased soil moisture which resulted in rapid crop growth and the production of number of total tillers plant^{-1} was higher. The result was partially similar to the findings of Misra (1996) who stated that soil mulching significantly enhanced the number of total tiller plant^{-1}.

The number of effective tillers plant^{-1} is the most important character which ensure a higher yield. Increased irrigation gave the highest number of effective tillers plant^{-1} (Tables 2.16a and 2.16b). Irrigation had significant influence on the number of effective tillers plant^{-1} in wheat (Patel *et al.*, 1971; Islam, 1997; Hefni *et al.*, 1983; Jana and Misra, 1995; Razi-us-shams, 1996; Sarker and Paul, 1997; Rahman *et al.*, 2001; Saren *et al.*, 2004; Rafiq *et al.*, 2005; Afzal *et al.*, 2006). Prodip produced higher number of effective tillers plant^{-1}and M_P produced the highest number of effective tillers plant^{-1} which was followed by M_S and M_W.

The significant effect of irrigation and mulching was observed on two wheat varieties (Tables 2.16a and 2.16b). Every experimental year rain-fed plants had the lowest spike length and I_3 treatment had the tallest spikes. Patel *et al.* (1971), Anonymous (1975), Muhammad-Jamal *et al.* (1996), Razi-us-shams (1996), Rahman and Paul (1998), Haider (2002) and Rahman (2004) reported similar results in wheat. Prodip produced longer spikes than Sufi. The longest spike was found in M_P followed by M_S and M_w.

The spike length of wheat varied significantly with different mulching treatments. The shortest spikes were produced with no mulch and the tallest spikes were produced by black polythene followed by rice straw and water hyacinth (Tables 2.16a and 2.16b). Mondal (2003) reported the similar result.

Different irrigation levels had significant effect on extrusion length of wheat (Tables 2.16a and 2.16b). The highest and lowest extrusion lengths were obtained from the highest irrigation (I_3) and no irrigation levels (I_0), respectively. Similar results were shown in wheat by Haider (2002) and in barley by Mollah (2007). Prodip showed higher extrusion length than Sufi. Black polythene produced the highest extrusion length followed by rice straw and water hyacinth.

The highest level of irrigation produced the highest number of spikelets spike^{-1} in the present study. The increased level of irrigation increased the number of spikelets spike^{-1}. Some previous studies opined similar results in wheat (Rawson, 1970; Saxena and Singh, 1979; Okuyama and Igarashi, 1990; Rahman *et al.*, 2001; Haider, 2002; Rahman, 2004; Khaleque, 2005). Between the varieties, the higher number of spikelets spike^{-1} was produced by Prodip in both growing seasons. Black polythene produced the highest number of spikelets spike^{-1}.

The number of fertile spikelets spike^{-1} varied significantly due to different irrigation levels. The highest irrigation level (6 cm of irrigation) produced the highest number of fertile spikelets spike^{-1} and no-irrigated plants produced the lowest number of fertile spikelets spike^{-1}. This result is supported by Angus and Sage (1980), Rahman *et al.* (2001), Rahman (2004) and Rafiq *et al.* (2005) in wheat and by Mollah (2007) in barley.

Prodip produced higher number of fertile spikelets spike^{-1} in both the years. Varietal differences regarding the number of fertile spikelets spike^{-1} were due to their differences in generic makeup. Black polythene produced the highest number of fertile spikelets spike^{-1} followed by rice straw and water hyacinth.

The significant effect of irrigation was observed on the number of sterile spikelets spike^{-1}. Increased irrigation levels significantly decreased the number of sterile spikelets spike^{-1} in both the years. The highest number of sterile spikelets spike^{-1} was obtained in rain-fed plants (I_0) followed by I_1 and I_2 treatments. The lowest number of sterile spikelets spike^{-1} was obtained from I_3 treatment. This result was supported by Hafiz (2007) in barley.

The 1000-grain weight is the most important yield component a stated by Petr *et al.* (1979). In the present study, I_3 treatment produced the highest 1000-grain weight and the lowest value was found in control (I_0) in each experimental year. Similar results were also reported in by previous studies such as Misra *et al.* (1969), Singh *et al.* (1980), Rahman and Paul (1998), Rahman *et al.* (2001) and Rafiq *et al.* (2005), and in barley by Borowczak *et al.* (2003) and Afzal *et al.* (2006). In contrast, some workers reported that 1000-grain weight decreased with the increase of irrigation levels (Pandit *et al.*, 2001). Prodip produced significantly higher 1000-grain weight in both the years which might be due to genetic constitution. In every experimental year, mulching was found to produce higher amount of 1000-grain weight over control. In the present study, black polythene produced the highest weight of 1000-grain followed by rice straw and water hyacinth mulches. No mulch produced the lowest weight of 1000-grain. This result revealed that mulching improved 1000-grain weight. Badaruddin *et al.* (1999) and Mondal (2003) also reported the same results in wheat.

Grain yield significantly increased with the increasing irrigation frequencies. The highest grain yield was produced by I_3 (6 cm of irrigation) treatment followed by I_2 and I_1 irrigation treatments. The lowest grain yield was recorded in non-irrigated rain-fed wheat varieties in both the years. Thus, it can be mentioned that grain yield was higher in the irrigated plants than in the rain-fed plants. similar results were recorded in wheat by Misra *et al.* (1969), Verma *et al.* (1970), Anonymous (1975), Pal *et al.* (1979), Saxena and Singh (1979), Malik (1980), Rahman *et al.* (1981), Rahman (1999), Rao and Bhardwaj (1981), Idris and Karim (1982), Quayyam and Kamal (1986), Upadhay and Debey (1991), BARI (1993), Singh and Uttam (1993), Jahiruddin *et al.* (1995), Saha and Paul (1995), Yadav *et al.* (1995), Rahman and Paul (1996), Rani *et al.* (2000), Shirazi *et al.* (2000), Fan *et al.* (2001), Pandit *et al.* (2001) and Pandey *et al.* (2001). Between the two varieties, Prodip produced higher grain yield than Sufi. Amongst different mulching treatments, black polythene produced significantly the highest grain yield in every year followed by rice straw and water hyacinth. No mulch always produced the lowest grain yield. This observation was similar with the findings of Dubey *et al.* (1993) and Mondal (2003) in wheat. Black polythene might have conserved the maximum amount of soil moisture for a longer period which helped the plants to grow vigorously and increased the spike length and 1000-grain weight that eventually resulted a higher grain yield. Quadir (1992) also confirmed that mulching with polythene was more effective compared to straw mulch in increasing grain yield.

The highest and the second highest irrigation levels produced higher straw yield and control or non-irrigated crop produced the lowest straw yield in both the years and varieties. Similar results were found by Jana and Misra (1995), Yadav *et al.* (1995), Razi-us-shams (1996) in wheat, and Al-Satari *et al.* (2001), Chaudhury and Sharma (2003) and Baheri *et al.* (2005) in barley. Prodip produced higher straw yield than Sufi in each experimental year. The highest straw yield was obtained from black polythene followed by rice straw and water hyacinth. No mulch always produced the lowest amount of straw yield. Similar finding was reported by Duncan *et al.* (1992) and Mondal (2003). Besides, Khondaker (1998) stated that mulching induced residual soil moisture ultimately increased the straw yield of rain-fed wheat.

Like straw yield, biological yield also followed the same pattern, and the highest and the second highest levels of irrigation produced higher biological yield. Between the two varieties, Prodip was superior to produce higher biological yield in both the years. In the present study, the highest amount of biological yield was produced from black polythene followed by rice straw and water hyacinth. No mulch produced the lowest amount of biological yield. This is because of the highest production of grain and straw yields by black polythene as biological yield is the sum of grain and straw yields. Similar result was observed by Du *et al.* (1997).

The highest value of harvest index (HI) was found in I_3 followed by I_2 and I_1 in both the experimental years. The lowest HI was observed in I_0 treatment. Similar results were reported by Keiralla *et al.* (1993), Singh and Patel (1995), Hoda *et al.* (1996), Baheri *et al.* (2005), Rafiq *et al.* (2005) and Xue *et al.* (2006). In contrast, Rahman *et al.* (2001) observed significantly higher HI in the rain-fed wheat plants.

Between the two wheat varieties, Prodip always produced higher HI value than Sufi. Amongst the mulching treatments, black polythene produced the highest value of HI followed by rice straw and water hyacinth. Mondal (2003) also reported the similar result. Badruddin *et al.* (1999) reported that mulch significantly increased HI.

From the overall discussion, it is understood that irrigated crops give better performance than the control. Amongst the irrigation levels, I_3 (6 cm of irrigation) treatment showed the highest values in TDM, LAI, CGR, MRC, RLWC, chlorophyll content and yield contributing characters. On the other hand, amongst the mulching treatments, black polythene produced the highest values in those parameters mentioned earlier. If both of these treatments (6 cm of irrigation and black polythene) are used properly, better growth and development, and higher yield of wheat can be achieved.

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APPENDICES

Appendix I: Morphological characteristics and chemical properties of soils of the experimental area

Constituents	Characteristics	Constituents	Results
Location	Western side of the Department of Agronomy & Agricultural Extension, University of Rajshahi, Rajshahi	pH	8.5
Land type	Medium high land	Organic matter (OM)	0.84 %
General soil type	Non calcarious dark grey soil	Total Nitrogen (N)	0.04 %
Agro-ecological zone	AEZ-11: High Ganges River Floodplain	Phosphorus (P_2O_5)	19.15 ppm
Topography	Fairly leveled	Potassium (K_2O)	0.27 %
Soil colour	Dark grey	Sulphur (S)	8.90 mili equivalent/ 100g soil
Drainage	Well drained	Zinc (Zn)	0.10 %

Source: The soil samples of the Agronomy field laboratory, Department of Agricultural Extension as examined by Soil Resources Development Institute, Regional Laboratory, Shyampur, Rajshahi

Appendix II: Meteorological data of 2008-2009 and 2009-2010 of the experimental area

A. Minimum and maximum average temperature (˚C) (monthly)

Month	2008-2009		2009-2010	
	Min	Max	Min	Max
July	25.98	31.95	26.60	33.50
August	26.37	32.77	26.40	32.90
September	25.84	33.30	26.20	32.90
October	22.56	31.79	22.30	33.40
November	16.55	29.59	17.80	29.20
December	15.04	25.01	11.90	24.70
January	12.35	24.49	9.38	22.39
February	13.50	31.50	13.11	28.79
March	17.96	33.39	19.81	35.94
April	23.89	37.44	25.66	38.32
May	24.40	34.90	25.41	35.90
June	26.60	36.70	26.07	35.02
Mean	**20.92**	**30.90**	**20.89**	**31.91**

B. Total amount of rainfall (mm) (monthly)

Month	2008-2009	2009-2010
July	221.5	186.7
August	245.5	240.1
September	127.5	282.3
October	121.0	45.0
November	0.0	0.0
December	0.0	0.0
January	1.0	0.0
February	7.0	2.2
March	27.9	0.0
April	0.0	39.2
May	130.0	86.2
June	127.6	206.7
Total	**1,009.0**	**1,088.4**

(Source: Regional Wheat Research Centre, BARI, Rajshahi, 2008, 2009, 2010)

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Appendix IIIa: Mean squares from analysis of variance for total dry matter (TDM) (g m^{-2}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	0.04	0.18	0.41	4.66	4.01	32.91	40.06	41.31	67.58
Irrigation levels (I)	3	48.87**	496.69**	1982.89**	16350.14**	25907.04**	66542.11**	118112.31**	166357.71**	144179.25**
Error	6	1.29	8.43	35.82	489.64	404.88	1012.55	2036.52	2544.66	2076.57
Variety (V)	1	1.08NS	10.17NS	79.50NS	91.05NS	2121.02NS	6268.95NS	14836.45NS	33814.14*	36224.89*
I×V	3	74.96**	494.59**	2172.31**	25940.44**	26577.30**	72056.96**	120727.56**	154801.64**	119291.81**
Error	8	1.69	10.97	54.64	618.22	641.71	2401.77	3794.22	6094.56	5719.72
Mulching (M)	3	11.35NS	89.89NS	372.63NS	1606.68NS	4984.49NS	14730.02NS	20254.40NS	30076.48NS	29206.73NS
I×M	9	11.00	72.73	318.42	4290.96	3929.25	9663.16	17601.02	23077.88	17845.48
V×M	3	4.57NS	81.87NS	341.26NS	1415.58NS	6851.34NS	19304.20NS	46870.94*	83246.90**	99148.21**
I×V×M	9	17.59	102.38	451.94	7484.38	5407.25	14129.56	24479.43	32178.43	25705.39
Error	48	6.61	46.82	207.33	1235.88	2704.11	7624.98	11975.07	18146.85	18242.13
CV %		16.13	16.42	16.70	20.50	16.72	17.24	16.26	16.20	15.98

Appendix IIIb: Mean squares from analysis of variance for total dry matter (TDM) ($g\ m^{-2}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	9.10	62.19	246.44	1249.49	4614.08	11295.71	20915.61	33514.19	34788.43
Irrigation levels (I)	3	231.35**	1673.82**	7287.30**	90055.64**	91223.04**	242607.80**	421846.48**	560072.59**	442082.33**
Error	6	0.08	1.67	5.41	43.42	42.05	106.35	182.66	166.72	111.36
Variety (V)	1	6.03**	65.02**	224.57**	1107.60**	4962.60**	11191.93**	34490.44**	79172.88**	119431.84**
I×V	3	0.05NS	0.60NS	1.83NS	18.73NS	46.11NS	63.02NS	155.67**	472.20*	596.86NS
Error	8	0.02	0.57	7.81	5.57	68.77	38.45	11.20	65.17	323.95
Mulching (M)	3	94.32**	638.01**	2869.37**	11374.70**	36864.21**	106020.04**	151201.10**	225185.56**	222564.38**
I×M	9	0.88	6.11	26.41	341.32	341.03	1074.87	1433.41	1828.83	1536.31
V×M	3	0.10NS	1.55NS	1.72NS	8.01NS	84.03NS	644.89NS	191.48NS	349.47NS	481.31NS
I×V×M	9	0.00	0.03	0.15	0.62	2.01	11.40	4.86	17.31	16.00
Error	48	0.14	1.93	6.97	16.06	53.81	157.45	180.24	313.99	226.92
CV %		2.33	3.23	2.96	2.26	2.26	2.36	1.90	2.02	1.69

Appendix IVa: Mean squares from analysis of variance for leaf area index (LAI) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000
Irrigation levels (I)	3	0.015**	0.091**	0.443**	5.498**	2.359**	2.678**	1.994**	0.254**	0.140*
Error	6	0.001	0.002	0.006	0.178	0.030	0.034	0.031	0.001	0.002
Variety (V)	1	0.000NS	0.001NS	0.009NS	0.120*	0.004NS	0.002*	0.021**	0.001NS	0.007*
I×V	3	0.029**	0.091**	0.424**	9.363**	2.529**	2.523**	1.920**	0.081**	0.081**
Error	8	0.001	0.002	0.008	0.222	0.035	0.085	0.032	0.002	0.003
Mulching (M)	3	0.005NS	0.016NS	0.073NS	0.328NS	0.537NS	0.742NS	0.336NS	0.106NS	0.040NS
I×M	9	0.004	0.013	0.058	1.542	0.370	0.357	0.279	0.013	0.015
V×M	3	0.001NS	0.002NS	0.003NS	0.026NS	0.055NS	0.167NS	0.012NS	0.009NS	0.031NS
I×V×M	9	0.007	0.018	0.080	2.833	0.494	0.472	0.368	0.010	0.020
Error	48	0.003	0.008	0.035	0.311	0.265	0.365	0.150	0.042	0.018
CV %		16.52	15.49	15.93	24.67	17.72	20.94	15.52	14.42	15.25

Appendix IVb: Mean squares from analysis of variance for leaf area index (LAI) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	0.003	0.013	0.117	0.432	0.364	0.331	0.253	0.070	0.023
Irrigation levels (I)	3	0.088**	0.290**	1.308**	31.495**	7.797**	7.648**	6.014**	0.271**	0.314**
Error	6	0.000	0.000	0.004	0.034	0.020	0.036	0.013	0.005	0.003
Variety (V)	1	0.001**	0.005**	0.012**	0.052**	0.147**	0.995**	0.027**	0.024*	0.154**
I×V	3	0.000NS	0.000NS	0.000NS	0.001NS	0.000NS	0.007NS	0.000NS	0.000NS	0.001NS
Error	8	0.000	0.000	0.004	0.005	0.041	0.005	0.009	0.005	0.001
Mulching (M)	3	0.038**	0.110**	0.501**	1.726**	3.981**	5.322**	2.127**	0.754**	0.254**
I×M	9	0.000	0.001	0.005	0.108	0.042	0.047	0.016	0.002	0.001
V×M	3	0.000NS	0.000NS	0.001NS	0.005NS	0.040*	0.332**	0.007NS	0.006NS	0.001NS
I×V×M	9	0.000	0.000	0.000	0.001	0.001	0.004	0.000	0.000	0.000
Error	48	0.000	0.001	0.002	0.010	0.014	0.026	0.023	0.005	0.002
CV %		6.01	5.46	4.17	4.39	4.06	5.59	6.06	5.05	4.93

Appendix Va: Mean squares from analysis of variance for crop growth rate (CGR) (g m^{-2} day^{-1}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.001	0.000	0.028	0.036	0.154	0.005	0.005	0.143
Irrigation levels (I)	3	2.543**	4.954**	76.664**	31.723**	94.136**	73.511**	41.950**	10.731*
Error	6	0.033	0.096	2.807	0.844	1.411	1.797	0.351	1.149NS
Variety (V)	1	0.046NS	0.328NS	0.004NS	13.334*	10.968NS	18.169*	38.552**	1.421NS
I×V	3	1.902**	5.947**	146.606**	63.779**	111.810**	63.032**	22.169*	28.331**
Error	8	0.045	0.170	3.575	1.797	6.084	1.765	3.139	0.765
Mulching (M)	3	0.375NS	0.966NS	4.341NS	9.386NS	25.917NS	5.020NS	9.956NS	0.882NS
I×M	9	0.283	0.870	24.647	6.206	12.831	12.334	4.191	4.667
V×M	3	0.494*	0.889NS	3.694NS	20.531NS	33.584*	64.284**	52.014**	9.263**
I×V×M	9	0.360	1.247	45.928	12.483	20.606	14.198	5.353	3.942
Error	48	0.187	0.573	5.085	5.826	12.753	6.126	6.812	1.175
CV %		16.79	16.98	26.45	17.30	18.28	14.86	16.49	14.86

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Appendix Vb: Mean squares from analysis of variance for crop growth rate (CGR) (g m^{-2} day^{-1}) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.24	0.61	3.87	10.65	15.09	16.99	15.95	0.43
Irrigation levels (I)	3	6.61**	19.76**	506.27**	160.17**	363.32**	246.34**	97.81**	81.11**
Error	6	0.01	0.03	0.51	0.39	0.62	0.53	1.23	0.77
Variety (V)	1	0.32**	0.48NS	3.35**	13.82**	12.49*	63.88**	91.51**	48.57*
I×V	3	0.00NS	0.01NS	0.09NS	0.12NS	0.58NS	1.37NS	0.88NS	0.08NS
Error	8	0.01	0.12	0.05	0.79	1.27	0.59	0.39	4.84
Mulching (M)	3	2.42**	8.02**	28.29**	73.30**	178.87**	44.13**	73.63**	1.55NS
I×M	9	0.02	0.07	1.95	0.65	2.08	0.39	0.29	0.38
V×M	3	0.01NS	0.01NS	0.07NS	0.66NS	8.69**	14.07**	0.70NS	0.85NS
I×V×M	9	0.00	0.00	0.01	0.01	0.15	0.23	0.14	0.44
Error	48	0.02	0.11	0.30	0.40	1.80	2.66	4.87	5.87
CV %		5.58	7.16	6.19	4.31	6.46	9.26	13.18	15.20

Appendix VIa: Mean squares from analysis of variance for relative growth rate (RGR) (g g^{-1} day^{-1}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.000**	0.000NS	0.001**	0.001**	0.000NS	0.000NS	0.000NS	0.000NS
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
I×V	3	0.000**	0.000NS	0.002**	0.002**	0.000NS	0.000*	0.000*	0.000**
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
I×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V×M	3	0.000**	0.000NS	0.000NS	0.000NS	0.000**	0.000**	0.000**	0.000**
I×V×M	9	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		2.56	1.33	9.84	11.04	3.57	8.39	4.57	14.65

Appendix VIb: Mean squares from analysis of variance for relative growth rate (RGR) (g g^{-1} day^{-1}) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20-30	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.000NS	0.000NS	0.006**	0.006**	0.000NS	0.000NS	0.000**	0.000**
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000**	0.000**	0.000*
I×V	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000**	0.000NS	0.000NS
I×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V×M	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000**	0.000**	0.000NS	0.000NS
I×V×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		4.03	6.13	5.51	3.33	5.82	8.93	12.60	14.02

Appendix VIIa: Mean squares from analysis of variance for net assimilation rate (NAR) (g cm^{-2} day^{-1}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.015**	0.001**	0.014**	0.096**	0.003NS	0.003NS	0.010NS	0.105**
Error	6	0.000	0.000	0.001	0.006	0.000	0.000	0.000	0.004
Variety (V)	1	0.004*	0.010*	0.006*	0.025*	0.015*	0.023**	0.117*	0.003NS
I×V	3	0.005*	0.000NS	0.045**	0.241**	0.001NS	0.004*	0.010NS	0.235**
Error	8	0.001	0.001	0.001	0.008	0.003	0.001	0.007	0.005
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.011NS	0.002NS	0.003NS
I×M	9	0.001	0.000	0.008	0.036	0.001	0.000	0.001	0.032
V×M	3	0.015**	0.007**	0.008**	0.021*	0.023**	0.069*	0.108**	0.047**
I×V×M	9	0.001	0.000	0.016	0.077	0.000	0.000	0.001	0.043
Error	48	0.001	0.000	0.001	0.007	0.002	0.007	0.007	0.008
CV %		4.73	4.00	7.48	14.19	6.60	13.38	9.89	16.05

Appendix VIIb: Mean squares from analysis of variance for net assimilation rate (NAR) (g cm^{-2} day^{-1}) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.000	0.002	0.001	0.000	0.000	0.004	0.006	0.002
Irrigation levels (I)	3	0.000NS	0.000NS	0.140**	0.833**	0.002NS	0.004NS	0.009NS	0.732**
Error	6	0.000	0.000	0.001	0.001	0.001	0.002	0.004	0.006
Variety (V)	1	0.003**	0.001NS	0.004*	0.005*	0.001NS	0.010**	0.184**	0.285*
I×V	3	0.000NS	0.000NS	0.000NS	0.000NS	0.001NS	0.001NS	0.001NS	0.000NS
Error	8	0.000	0.001	0.001	0.001	0.003	0.001	0.003	0.034
Mulching (M)	3	0.001NS	0.000NS	0.000NS	0.005**	0.011**	0.088**	0.008NS	0.018NS
I×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
V×M	3	0.000NS	0.000NS	0.000NS	0.000NS	0.002NS	0.059**	0.001NS	0.005NS
I×V×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Error	48	0.001	0.002	0.001	0.001	0.002	0.005	0.012	0.040
CV %		6.07	7.07	5.71	4.90	6.58	10.09	12.22	15.58

Appendix VIIIa: Mean squares from analysis of variance for leaf area ratio (LAR) ($cm^2\ g^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.253	0.081	0.567	0.159	0.014	0.108	0.000	0.014
Irrigation levels (I)	3	16.897NS	43.317NS	629.038**	228.773**	16.662NS	15.685NS	3.724NS	2.586**
Error	6	0.548	0.563	12.878	10.375	0.153	0.135	0.244	0.182
Variety (V)	1	194.001**	444.492*	568.037*	353.818*	123.352**	72.941**	35.466**	5.990*
I×V	3	1.442NS	14.124NS	648.650**	447.461**	4.404*	2.713*	10.966*	7.718**
Error	8	16.001	19.351	44.507	31.212	1.085	0.679	2.602	0.599
Mulching (M)	3	1.708NS	2.960NS	1.895NS	15.737NS	16.150NS	4.858NS	0.310NS	0.078NS
I×M	9	2.009	3.920	100.404	64.387	0.948	0.658	1.810	1.083
V×M	3	317.499**	464.276**	451.828**	362.309**	206.748**	125.019**	52.599**	10.251**
I×V×M	9	1.700	3.798	212.592	133.629	0.356	0.684	2.924	1.747
Error	48	18.534	23.729	39.285	37.116	19.567	8.085	3.249	0.708
CV %		2.67	3.57	4.78	5.64	6.13	6.21	7.00	6.19

Appendix VIIIb: Mean squares from analysis of variance for leaf area ratio (LAR) ($cm^2\ g^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	3.40	94.98	183.45	19.80	0.20	0.29	0.79	0.29
Irrigation levels (I)	3	2.12NS	3.77NS	2415.60**	1430.55**	6.58NS	6.65NS	25.60**	18.81**
Error	6	8.44	0.85	2.73	4.31	4.92	2.40	0.58	0.06
Variety (V)	1	82.87**	81.07*	105.90*	80.56**	12.44NS	0.02NS	26.31**	1.38*
I×V	3	0.23NS	1.76NS	1.21NS	1.93NS	0.80NS	0.46NS	0.05NS	0.01NS
Error	8	5.44	7.30	17.18	1.11	2.67	1.61	0.56	0.17
Mulching (M)	3	1.28NS	0.79NS	4.52NS	97.30NS	160.84**	41.31**	2.44*	0.70*
I×M	9	0.51	0.28	0.12	0.21	0.17	0.20	0.06	0.02
V×M	3	0.23NS	3.21NS	6.81NS	12.27NS	41.73**	18.94**	0.70NS	0.10NS
I×V×M	9	1.24	1.14	0.66	0.31	0.23	0.03	0.02	0.00
Error	48	28.49	21.58	13.46	8.62	5.42	1.66	0.68	0.20
CV %		3.39	3.52	2.90	2.83	3.40	2.97	3.39	3.50

Appendix IXa: Mean squares from analysis of variance for relative leaf growth rate (RLGR) ($cm^2\ cm^{-2}\ day^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.000**	0.000**	0.002**	0.003**	0.000NS	0.000NS	0.001**	0.000*
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000*	0.000*	0.000**	0.000**	0.000NS	0.000NS	0.000NS	0.000*
I×V	3	0.000**	0.000**	0.006**	0.006**	0.000NS	0.000NS	0.002**	0.000**
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
I×M	9	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
V×M	3	0.000**	0.000**	0.000NS	0.000NS	0.000**	0.000*	0.000NS	0.000**
I×V×M	9	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.000
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		3.55	2.21	20.33	20.49	26.02	18.46	10.68	10.82

Appendix IXb: Mean squares from analysis of variance for relative leaf growth rate (RLGR) ($cm^2\ cm^{-2}\ day^{-1}$) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.000NS	0.000NS	0.020**	0.020**	0.000NS	0.000NS	0.005NS	0.001NS
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.000NS	0.000NS	0.000NS	0.000NS	0.001**	0.001NS	0.000NS	0.001NS
I×V	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000**	0.001**	0.001NS	0.000NS	0.000NS
I×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V×M	3	0.000NS	0.000NS	0.000NS	0.000NS	0.001**	0.001**	0.000NS	0.000NS
I×V×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		13.85	8.71	9.79	16.71	24.83	17.05	14.53	15.03

Appendix Xa: Mean squares from analysis of variance for specific leaf area (SLA) ($cm^2 g^{-1}$) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	1.148	0.784	0.995	2.060	2.147	0.033	3.200	3.620	2.548
Irrigation levels (I)	3	131.100**	31.306**	422.246**	167.420**	13.177NS	196.282**	153.465**	95.658**	18.879*
Error	6	0.399	1.151	3.010	1.332	1.130	1.439	2.418	3.788	3.845
Variety (V)	1	6.623*	1.118NS	145.447**	48.958**	1.182NS	1.334NS	1.530*	22.413*	6.510NS
I×V	3	24.995**	1.044NS	80.856**	13.169**	56.505**	58.554**	8.993**	7.394NS	2.138NS
Error	8	1.374	1.482	5.707	1.643	2.463	1.095	0.524	3.552	16.751
Mulching (M)	3	8.165NS	2.156NS	11.732NS	8.477NS	431.575NS	2.624NS	3.857NS	6.078NS	8.628NS
I×M	9	7.983	2.123	17.632	3.373	11.402	3.422	3.563	7.244	16.516
V×M	3	9.251NS	5.936*	40.972**	1.135NS	3.208NS	5.326NS	12.259*	0.895NS	8.776NS
I×V×M	9	7.337	4.860	15.413	8.077	6.951	4.366	13.482	2.673	4.038
Error	48	7.242	1.491	4.402	5.651	223.141	2.819	4.243	11.110	7.489
CV %		1.02	0.49	0.78	0.96	6.18	0.74	0.93	1.51	1.40

Appendix Xb: Mean squares from analysis of variance for specific leaf area (SLA) (cm^2 g^{-1}) at different days after sowing (2009- 2010)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	78.16	36.59	751.75	351.79	17.55	97.48	3.60	13.30	28.69
Irrigation levels (I)	3	5.29NS	7.55NS	77.79NS	1.32NS	77.92*	62.18NS	37.78NS	32.40NS	10.54NS
Error	6	32.43	17.17	72.53	13.15	13.98	68.36	59.16	39.12	56.82
Variety (V)	1	1.20NS	0.76NS	9.63NS	1.86NS	4.14NS	162.72NS	0.02NS	1.60NS	6.27NS
I×V	3	6.89NS	0.31NS	29.00NS	6.53NS	13.34NS	4.92NS	1.32NS	4.86NS	7.39NS
Error	8	13.36	13.20	45.58	109.68	9.96	110.46	46.64	30.07	10.58
Mulching (M)	3	37.74NS	1.09NS	7.82NS	7.60NS	3983.53**	7.36NS	33.66NS	75.01NS	9.14NS
I×M	9	4.62	0.53	4.39	4.19	3.69	1.64	7.09	5.10	3.53
V×M	3	11.57NS	0.63NS	20.95NS	5.42NS	1.01NS	0.43NS	3.68NS	9.03NS	0.18NS
I×V×M	9	4.84	2.32	5.32	3.65	2.77	1.55	0.37	1.27	1.80
Error	48	145.23	111.98	57.86	43.83	99.55	60.14	101.12	52.66	34.42
CV %		4.53	4.21	2.84	2.69	4.12	3.43	4.52	3.28	3.00

Appendix XIa: Mean squares from analysis of variance for leaf weight ratio (LWR) (g g^{-1}) at different days after sowing (2008-2009)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.001**	0.000NS	0.000NS	0.015**	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
Error	6	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.002*	0.004**	0.005**	0.006*	0.004**	0.001**	0.002**	0.000*	0.000**
I×V	3	0.000NS	0.000NS	0.000NS	0.036**	0.000NS	0.000NS	0.000NS	0.001**	0.000*
Error	8	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
I×M	9	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000
V×M	3	0.003**	0.006**	0.007**	0.006**	0.006**	0.003**	0.002**	0.001**	0.000**
I×V×M	9	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000
Error	48	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
CV %		2.22	3.43	3.81	6.71	4.82	7.40	6.78	8.43	4.26

Appendix XIb: Mean squares from analysis of variance for leaf weight ratio (LWR) (g g^{-1}) at different days after sowing (2009-2010)

Sources of variation	df	Days after sowing (DAS)								
		20	30	40	50	60	70	80	90	100
Replication	2	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Irrigation levels (I)	3	0.000NS	0.000NS	0.000NS	0.122NS	0.000NS	0.000NS	0.000**	0.002**	0.000**
Error	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Variety (V)	1	0.002**	0.001**	0.001**	0.002**	0.001NS	0.001**	0.001**	0.000**	0.000*
I×V	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS	0.000NS
Error	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mulching (M)	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000**	0.003NS	0.000NS	0.000NS	0.000NS
I×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V×M	3	0.000NS	0.000NS	0.000NS	0.000NS	0.000**	0.002**	0.000NS	0.000NS	0.000NS
I×V×M	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Error	48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CV %		1.38	2.48	2.21	2.34	1.81	3.25	3.54	3.82	4.04

Appendix XIIa: Mean squares from analysis of variance for the moisture retention capacity (MRC) (%) of flag leaf of wheat (2008-2009)

Sources of variation	df	Time of the day									
		8.30 am	9.00 am	9.30 am	10.00 am	10.30 am	11.00 am	12.00 noon	1.00 pm	2.00 pm	3.00 pm
Replication	2	224.330	229.450	198.435	218.957	203.398	205.278	207.432	199.353	214.802	220.537
Irrigation levels (I)	3	331.320**	380.730**	567.706**	428.569**	327.894**	190.850**	326.736**	356.022**	360.577**	317.900**
Error	6	7.260	6.628	7.389	7.056	5.118	5.162	5.550	6.790	7.445	7.757
Variety (V)	1	1468.127**	1678.688**	1486.014**	1181.536**	1108.536**	1564.047**	1072.876**	1030.053**	981.824**	895.726**
I×V	3	52.229	65.035	69.496	30.819	33.357	101.049	43.544	26.185	42.888	28.640
Error	8	9.620	8.263	7.742	5.768	7.620	6.560	6.221	7.500	8.232	8.860
Mulching (M)	3	464.126**	294.252**	284.240**	369.547**	441.218**	414.793**	468.811**	381.129**	524.141**	318.554**
I×M	9	5.898NS	7.347NS	8.707NS	5.402NS	6.168NS	22.486**	5.535NS	5.709NS	9.541NS	6.788NS
V×M	3	16.880	2.707	3.277	13.332	7.711	21.027	4.550	4.616	5.714	7.890
I×V×M	9	9.039	14.491	10.240	7.768	5.064	27.048	6.930	9.271	8.196	10.252
Error	48	8.991	8.356	7.771	7.022	7.177	6.773	6.358	7.000	8.166	9.027
CV %		4.10	4.14	4.05	3.92	4.06	4.11	4.06	4.36	4.79	5.32

Appendix XIIb: Mean squares from analysis of variance for the moisture retention capacity (MRC) (%) of flag leaf of wheat (2009-2010)

Sources of variation	df	Time of the day									
		8.30 am	**9.00 am**	**9.30 am**	**10.00 am**	**10.30 am**	**11.00 am**	**12.00 noon**	**1.00 pm**	**2.00 pm**	**3.00 pm**
Replication	2	490.528	546.301	500.957	559.215	534.914	540.759	522.984	491.934	545.745	531.395
Irrigation levels (I)	3	319.245**	328.085**	567.212**	424.219**	331.905**	218.931**	341.495**	367.665**	389.736**	313.786**
Error	6	5.287	7.257	5.256	9.218	7.975	7.835	6.261	6.509	6.739	7.500
Variety (V)	1	1433.142**	1700.167**	1455.094**	1224.082**	1155.649**	1579.341**	1103.174**	1017.969**	1004.079**	903.563**
I×V	3	51.916	109.380	77.623	60.636	37.711	85.694	49.496	27.592	26.879	26.363
Error	8	6.891	8.300	6.428	9.627	10.025	8.538	6.592	7.826	8.929	9.470
Mulching (M)	3	439.162**	289.761**	273.405**	383.756**	457.832**	462.574**	467.774**	385.567**	526.761**	315.094**
I×M	9	3.703NS	9.834NS	7.748NS	11.215NS	7.312NS	13.855NS	6.370NS	6.628NS	8.049NS	7.217NS
V×M	3	14.329	1.334	1.872	14.125	7.228	7.191	4.734	4.637	6.504	8.251
I×V×M	9	6.712	13.106	8.160	8.423	6.651	22.353	8.382	10.445	11.973	10.410
Error	48	6.536	7.326	6.215	9.556	8.697	8.564	7.332	7.331	8.524	9.258
CV %		3.50	3.87	3.62	4.56	4.47	4.61	4.44	4.46	4.90	5.39

Appendix XIIIa: Mean squares from analysis of variance for relative leaf water content (RLWC) of flag leaf of wheat (2008-2009)

Sources of variation	df	Time of the day		
		8.00 am	12.00 noon	4.00 pm
Replication	2	638.806	612.443	595.725
Irrigation levels (I)	3	496.298**	399.389**	590.125**
Error	6	2.418	6.240	8.966
Variety (V)	1	1555.340**	1460.082**	1723.900**
I×V	3	115.904	51.348	99.814
Error	8	2.205	4.720	4.061
Mulching (M)	3	416.519**	161.327**	246.712**
I×M	9	1.837NS	5.605NS	15.411*
V×M	3	8.767	1.202	3.585
I×V×M	9	4.082	3.144	5.814
Error	48	2.992	5.697	5.585
CV %		2.14	3.82	2.99

Appendix XIIIb: Mean squares from analysis of variance for relative leaf water content (RLWC) of flag leaf of wheat (2009-2010)

Sources of variation	df	Time of the day		
		8.00 am	12.00 noon	4.00 pm
Replication	2	634.767	659.945	635.552
Irrigation levels (I)	3	529.041**	345.920**	697.768**
Error	6	2.352	4.723	3.662
Variety (V)	1	1645.236**	1350.675**	1783.392**
I×V	3	150.769	74.096	122.333
Error	8	8.614	6.786	5.060
Mulching (M)	3	522.111**	341.727**	316.578**
I×M	9	10.320*	6.429NS	11.983*
V×M	3	2.868	3.373	5.077
I×V×M	9	11.786	10.423	6.756
Error	48	5.721	5.882	5.192
CV %		2.89	3.73	2.84

Appendix XIVa: Mean squares from analysis of variance for chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2008-2009

Sources of variation	df	Chlorophyll content of flag leaf (mg dm^{-2})			
		Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
Replication	2	0.630	0.115	1.278	0.013
Irrigation levels (I)	3	4.337**	1.250**	10.267**	0.017NS
Error	6	0.015	0.001	0.016	0.013
Variety (V)	1	2.112**	0.187**	3.554**	0.251NS
I×V	3	0.033	0.003	0.051	0.006
Error	8	0.009	0.001	0.008	0.012
Mulching (M)	3	1.193**	0.383**	2.923**	0.014NS
I×M	9	0.019*	0.001NS	0.023**	0.016**
V×M	3	0.014	0.001	0.014	0.014
I×V×M	9	0.008	0.001	0.007	0.011
Error	48	0.008	0.001	0.007	0.013
CV (%)		4.00	2.88	2.38	6.16

Appendix XIVb: Mean squares from analysis of variance for chlorophyll content (mg dm^{-2}) of wheat flag leaf in 2009-2010

Sources of variation	df	Chlorophyll content of flag leaf (mg dm^{-2})			
		Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Chlorophyll a:b
Replication	2	1.722	0.470	3.969	0.015
Irrigation levels (I)	3	4.675**	1.577**	11.682**	0.024NS
Error	6	0.021	0.020	0.080	0.006
Variety (V)	1	2.297**	0.355**	4.481**	0.132**
I×V	3	0.031	0.032	0.119	0.010
Error	8	0.008	0.016	0.047	0.006
Mulching (M)	3	1.290**	0.509**	3.405**	0.032**
I×M	9	0.017**	0.019NS	0.065NS	0.009NS
V×M	3	0.011	0.019	0.055	0.009
I×V×M	9	0.005	0.016	0.041	0.008
Error	48	0.006	0.016	0.040	0.007
CV (%)		3.20	9.94	5.52	4.47

Appendix XVa: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2008-2009)

Sources of variation	df	Plant height (cm)	Number of total tillers plant^{-1}	Number of effective tillers plant^{-1}	Number of non-effective tillers plant^{-1}	Spike length (cm)	Extrusion length (cm)	Number of spikelets spike^{-1}
Replication	2	446.042	2.555	1.202	0.259	62.598	64.019	18.562
Irrigation levels (I)	3	5103.755**	8.733**	12.709**	0.524**	399.059**	526.530**	208.988**
Error	6	5.958	0.030	0.022	0.031	0.352	0.303	0.221
Variety (V)	1	7120.298**	2.181**	3.844**	0.239*	541.357**	631.913**	294.245**
I×V	3	62.018	0.024	0.010	0.047	3.181	4.207	2.446
Error	8	5.274	0.048	0.010	0.030	0.508	0.360	0.256
Mulching (M)	3	2637.892**	7.781**	12.334**	0.524**	245.489**	265.251**	119.585**
I×M	9	23.485**	0.034NS	0.011**	0.015NS	1.359**	1.672**	0.792**
V×M	3	58.119	0.064	0.059	0.013	3.761	3.392	1.748
I×V×M	9	6.072	0.062	0.019	0.024	0.769	0.537	0.364
Error	48	3.771	0.048	0.009	0.029	0.476	0.307	0.201
CV (%)		2.52	4.92	2.89	15.82	3.12	2.26	2.73

(Continued)

Appendix XVa: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2008-2009)

Sources of variation	df	Number of fertile spikelets spike^{-1}	Number of sterile spikelets spike^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
Replication	2	23.072	0.492	142.476	1.648	7.550	16.275	2.177
Irrigation levels (I)	3	162.253**	5.538**	1913.080**	12.583**	11.542**	43.630NS	201.130**
Error	6	0.489	0.299	1.268	0.018	0.101	0.182	0.382
Variety (V)	1	76.238**	70.916**	2083.766**	1.330**	0.163**	0.557**	63.278**
I×V	3	1.851	0.886	11.718	0.013	0.391	0.402	3.526
Error	8	0.258	0.159	1.961	0.022	0.134	0.167	1.231
Mulching (M)	3	383.738**	77.644**	1074.490**	7.421**	6.429**	27.120**	76.734**
I×M	9	1.535**	2.472**	5.788**	0.056*	0.493**	0.305NS	6.749**
V×M	3	1.959	3.264	8.868	0.055	0.947	1.385	3.136
I×V×M	9	0.617	1.022	2.934	0.026	0.157	0.292	0.479
Error	48	0.216	0.284	1.942	0.022	0.134	0.218	0.827
CV (%)		3.96	11.32	2.99	4.05	5.43	4.49	2.61

Appendix XVb: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2009-2010)

Sources of variation	df	Plant height (cm)	Number of total tillers plant^{-1}	Number of effective tillers plant^{-1}	Number of non-effective tillers plant^{-1}	Spike length (cm)	Extrusion length(cm)	Number of spikelets spike^{-1}
Replication	2	346.955	2.623	0.684	5.956	37.895	50.815	17.342
Irrigation levels (I)	3	6420.825**	10.494**	14.512**	0.508**	430.353**	604.568**	216.108**
Error	6	14.907	0.037	0.019	0.043	1.087	1.750	0.138
Variety (V)	1	8922.977**	2.496**	4.429**	0.271*	583.416**	735.491**	315.303**
I×V	3	52.813	0.025	0.005	0.040	3.225	5.209	2.218
Error	8	7.594	0.051	0.006	0.050	0.841	1.141	0.240
Mulching (M)	3	3435.545**	8.989**	13.944**	0.555**	264.994**	309.925**	127.043**
I×M	9	19.249**	0.036NS	0.016**	0.024NS	1.366*	2.395*	0.725*
V×M	3	51.687	0.073	0.052	0.004	3.669	4.338	1.551
I×V×M	9	7.908	0.068	0.028	0.018	0.956	1.577	0.475
Error	48	5.242	0.053	0.006	0.050	0.650	1.062	0.261
CV (%)		2.65	4.79	2.14	18.10	3.53	4.01	3.03

(Continued)

Appendix XVb: Mean squares from analysis of variance for yield and yield contributing characters of wheat (2009-2010)

Sources of variation	df	Number of fertile spikelets spike^{-1}	Number of sterile spikelets spike^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
Replication	2	11.063	0.797	170.029	1.527	3.827	10.173	2.662
Irrigation levels (I)	3	276.325**	3.771**	2000.580**	10.352**	11.275**	39.174**	176.007**
Error	6	0.106	0.166	0.877	0.023	0.035	0.054	0.343
Variety (V)	1	327.266**	0.107NS	2166.475**	14.485**	26.471**	80.045**	55.040**
I×V	3	3.309	0.423	12.802	0.125	0.216	0.082	4.297
Error	8	0.080	0.160	0.817	0.022	0.047	0.106	0.255
Mulching (M)	3	152.007**	1.132**	1068.176**	5.612**	6.712**	24.220**	52.508**
I×M	9	0.663**	0.128NS	10.317**	0.056**	0.449**	0.263*	6.452**
V×M	3	2.280	0.168	15.245	0.119	0.104	0.354	1.052
I×V×M	9	0.259	0.064	1.408	0.025	0.162	0.182	1.886
Error	48	0.057	0.180	0.985	0.018	0.052	0.103	0.253
CV (%)		1.62	20.61	2.06	3.98	3.42	3.19	1.50