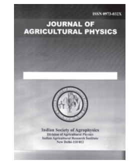
Vol. 17, No. 1, pp. 1-15 (2017)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in



Review Article

Microclimatic Modifications to Manage Extreme Weather Vulnerability and Climatic Risks in Crop Production

P.K. KINGRA* AND HARLEEN KAUR

School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana-141004, Punjab

ABSTRACT

Agriculture is highly dependent on prevailing weather conditions. Significant fluctuations and increased frequency of extreme weather events such as floods, droughts, heat and cold waves, hailstorms, strong winds, cyclones etc. have made agriculture more vulnerable to climatic risks. Global warming and climate changes are expected to increase in future. All these changes are likely to have severe implications on agricultural production especially in the tropical and sub-tropical regions including India. Increase in temperature is likely to have adverse effect on crop productivity due to shortened crop duration and increased respiratory losses. Erratic precipitation patterns are expected to enhance year-to-year yield fluctuations because of increased frequency and intensity of droughts and floods. Microclimate, referring to the climatic elements in the immediate vicinity of the plants, is very important as it regulates and determines the plant physiological reactions and energy exchange processes between the plant and its surrounding atmosphere. Lack of optimal climatic elements leads to disturbances in these processes and results in undesired decrease in crop productivity. Microclimatic modifications help in modifying the adverse conditions prevailing in the immediate vicinity of the plants making it favourable for the better crop growth, development and yield. Artificial control of field microclimate to maintain the optimum conditions for better plant growth and crop production can be achieved by making field level adjustments. short term adjustments at the farm level such as appropriate sowing time, row spacing and orientation, changes in crop rotation and crop cultivars, changes in soil cultivation and tillage practices, planting method, mulch application, use of shelterbelts / wind breaks and intercropping etc. result in the maintenance of favourable crop microclimate by moderating temperature extremes, conserving soil moisture and increasing radiation interception. Under the present scenario of global warming and increased occurrence of extreme weather events, adoption of such microclimatic modifications in crop production is the need of the hour to manage extreme weather risks and improve crop productivity to attain food security and sustainability of natural resources under changing climatic conditions.

Key words: Climate change, Extreme weather events, Microclimatic modifications, Radiation interception, Crop productivity

Introduction

Increase in the frequency of extreme weather events due to global warming triggered climate changes have resulted in manifold increase in vulnerability and climatic risks in agriculture. Inter- and intra-seasonal weather variability and extreme weather events like droughts, floods, heat and cold waves, strong winds, hailstorms, cyclones etc. have increased over the recent

*Corresponding author,
Email: pkkingra@pau.edu

decades (Singh and Kalra, 2016). Heat waves or extreme temperature events are projected to become more intense, frequent and last longer than what is being currently observed (Meehl *et al.*, 2007). Although climate change also occurs due to natural processes such as variations in solar output, earth's orbital changes and volcanic eruptions etc., but at present, climate change is happening mainly due to the human activities. Total anthropogenic green house gas emissions have been observed highest in the human history during the period 2000-2010 (IPCC, 2014). Major processes which contribute towards climate change are burning of fossil fuels, industrial processes, deforestation and agriculture. Among various green house gases, carbon dioxide contributes by 76%, methane by 16%, nitrous oxides by 6% and chlorofluorocarbons by 2% (IPCC, 2014). Agriculture contributes 28% of the Indian greenhouse gas emissions primarily through methane emission from paddy fields, enteric fermentation in ruminant animals and nitrous oxides from application of manures and fertilizers to the soil (Aggarwal, 2008).

As a consequence of these processes, global temperature has increased by 0.85°C during last 100 years. Average precipitation has increased over different regions of earth. These changes have resulted in melting of polar ice and glaciers leading to rise in sea levels and floods over various regions (IPCC, 2014). Global warming and climatic changes are expected to increase in future. Global circulation models have predicted rise in global average temperature by about 2°C by 2100. Although total precipitation is also predicted to increase during *kharif* season, but trends may vary at local level. Similarly, atmospheric CO_2 concentration is projected to increase from 478 to 1100 ppm by the end of the 21^{st} century (IPCC, 2007). Under such conditions, snow cover is expected to contract and frequency and intensity of extreme weather events like heat and cold waves, intense rainfall events etc. are likely to increase. There are evidences of increased heavy precipitation and decreased light precipitation in widespread parts of the globe due to global warming (Sai *et al.*, 2016). Due to highly erratic rainfall, there is an increased risk of drought as a result of increased prolonged dry spells, total dry days and decreased light precipitation days over India as a consequence of global warming (Mishra and Liu, 2014).

All these changes are likely to have severe implications on agricultural production especially in the tropical and sub-tropical regions including India. Hatfield and Prueger (2015) reported that warmer temperatures and more extreme temperature events will significantly impact plant productivity. Frost cause sterility and abortion of formed grains, while excessive heat cause reduction in grain number and reduced duration of the grain filling period (Barlow *et al.*, 2015). Under these scenarios, crop production in India is likely to decrease by 10-40% despite the beneficial effects of higher CO_2 on crop growth (Aggarwal, 2008). As *rabi* season crops are adapted to cooler conditions, thus greater losses are expected in *rabi* crops. Every 1^{o}C increase in temperature can reduce wheat production by 4-5 million tonnes in India (Aggarwal, 2008), however, timely planting can reduce these losses to 1-2 million tones. Similarly uncertainty in rainfall leading to droughts and floods is likely to enhance year-to-year yield fluctuations. However, reduced frequency of frost under warming scenarios may prove beneficial for frost sensitive crops like potato, peas etc.

Thus, agriculture is highly dependent on climatic conditions, but significant fluctuations and increased frequency of extreme weather events have made it more vulnerable by increasing climatic risks in crop production. Under such conditions, there is a dire need to manage climate change impacts on crop production to ensure food security for burgeoning population along with sustainability of natural resources. Since rise in temperatures are likely to reduce crop yield, thus it is imperative that suitable adaptation strategies have to be developed to minimize the adverse impacts (Rao and Rao, 2016). Gangwar *et al.* (2016) reported that location specific and integrated farming system based technological management options reduce the climatic risks and better utilization of available natural resources result in higher agricultural productivity and thereby enhance food and livelihood security of small and marginal farmers. Microclimatic modifications can be an effective adaptation strategy in this direction. Microclimate refers to climatic conditions in a smaller area i.e. a few meters above or below the earth surface or within the crop canopy (Yoshino, 1974). It is the local climatic condition near the ground or area around the plants (upto about 2m height) resulting from the general climatic conditions (Maliwal, 2011). It also refers to the climate of small regions influenced by the effects of the relief, topography and the lower surface features, which create disparity between soil and air temperature, humidity and wind speed (Bishnoi, 2010). Growth/development of plants mainly depends on their genetic constitution and environmental conditions. Climatic elements in the immediate vicinity of the plants are very important as they regulate and determine the physiological reactions. Lack of optimal climatic elements leads to disturbance in plant physiological and energy exchange processes resulting in undesired decrease in crop productivity. Under such conditions, there is a dire need to adopt microclimatic modifications to manage climate change impacts on crop production to ensure food security for burgeoning population along with sustainability of natural resources.

Microclimate of the crop varies from top to bottom of the canopy. All the crop management practices namely sowing time, planting method, row spacing, intercropping, tillage practices, mulch application, shelter belts and irrigation management etc. affect the microclimate due to their effect on canopy temperature, wind speed, soil moisture, light interception and rate of water loss etc. In other words, these microclimatic modifications affect the rate of exchange processes within the canopy as well as between the canopy and the surrounding air. Thus, by making some alterations / adjustments in crop management, we can modify the crop microclimate without any significant financial burden. Microclimate modification includes any artificially induced changes in the composition, behaviour or dynamics of the atmosphere near the ground so as to improve the environment in which the crops are grown. By making such alterations, the microclimate can be made more favourable for better growth and yield of the crops (Mahi and Kingra, 2013).

Processes of microclimatic modifications

Microclimatic modification is any process in which all the adverse or stress conditions prevailing in the immediate vicinity of the plants are modified for the better crop growth, development and yield. Artificial control of plant environment to maintain the optimum conditions for better plant growth and crop production is a future trend in agrometeorological research. Short term adjustments at the farm level involve production techniques, such as changes in crop rotation and crop cultivars, changes in soil cultivation and tillage practices, a shift of sowing dates, adapted fertilization and crop protection measures (Tubiello *et al*., 2000; Chen and McCarl, 2001; Alexandrov *et al*., 2002; Ghaffari *et al*., 2002; Trnka *et al*., 2004).

Long-term adaptations, on the contrary, include major structural changes of farm production systems and need careful agro-economic planning and realization at societal level; these adaptations also involve a set of sectors and stakeholders, such as policy, research, water and land planning (Eitzinger *et al*., 2010; Olesen *et al*., 2011). Some examples of long-term adjustments are changes in land use and landscape structure, breeding and biotechnology applications, crop substitution and changes in the farm production type (Alexandrov *et al*., 2002). A change in the landscape structure, such as the introduction of windbreaks or hedges, influence the microclimate of crops in neighbouring fields, mainly by slowing down the wind speed. Further effects include increased dew formation and leaf-wetness duration and a reduction of dry air advection, evapotranspiration, unproductive water loss and wind erosion (Cleugh, 1998).

Major processes of microclimatic modifications include controlling of heat load, water balance, wind speed and modification of temperature and solar radiation. Heat load on crop canopy can be increased (during winter) called heat trapping, or decreased (during summer) called heat evasion. Heat evasion can be achieved by shading the crop, irrigation management or by using anti-transpirants, whereas heat trapping can be achieved by adopting appropriate row direction or plant density (Mavi, 1994). Controlling the water balance involves increasing the amount of water stored in the root zone (by strip cropping, contour cropping, ploughing, terracing or bunding), increasing infilteration (by increasing tillage or increasing row spacing), reducing soil evaporation (by using mulches and crop residues, plastic covers or thick cultivatopn crops), modifying transpiration (by using anti-transpirants, substances forming film on leaf surface, stomata closing materials and reflectants). Whereas, winds can be controlled by applying wind breaks or shelter belts. These protections reduce wind speed on the leeward side and save the plants from freezing injury and mechanical damage (Fig. 1).

Modification of solar radiation can be accomplished by increasing the surface absorptive power, reflective power of the surrounding objects, exposure through site selection, increasing the radiant energy by fog dissipation and by adopting appropriate row direction. Similarly, soil temperature can be modified by mulch application and soil tillage etc. Mulch helps in reducing the soil temperature in summer and increasing during winter season. Similarly soil tillage by harrowing or inter-cultivation also helps in modifying the soil thermal regime. Similarly, protected cultivation under controlled environment like green houses (for temperature, humidity and CO_2 control), poly houses (naturally ventilated or with controlled environment) and shade houses (for crop production in warm climate) provide other means for raising crops under controlled microclimatic conditions.

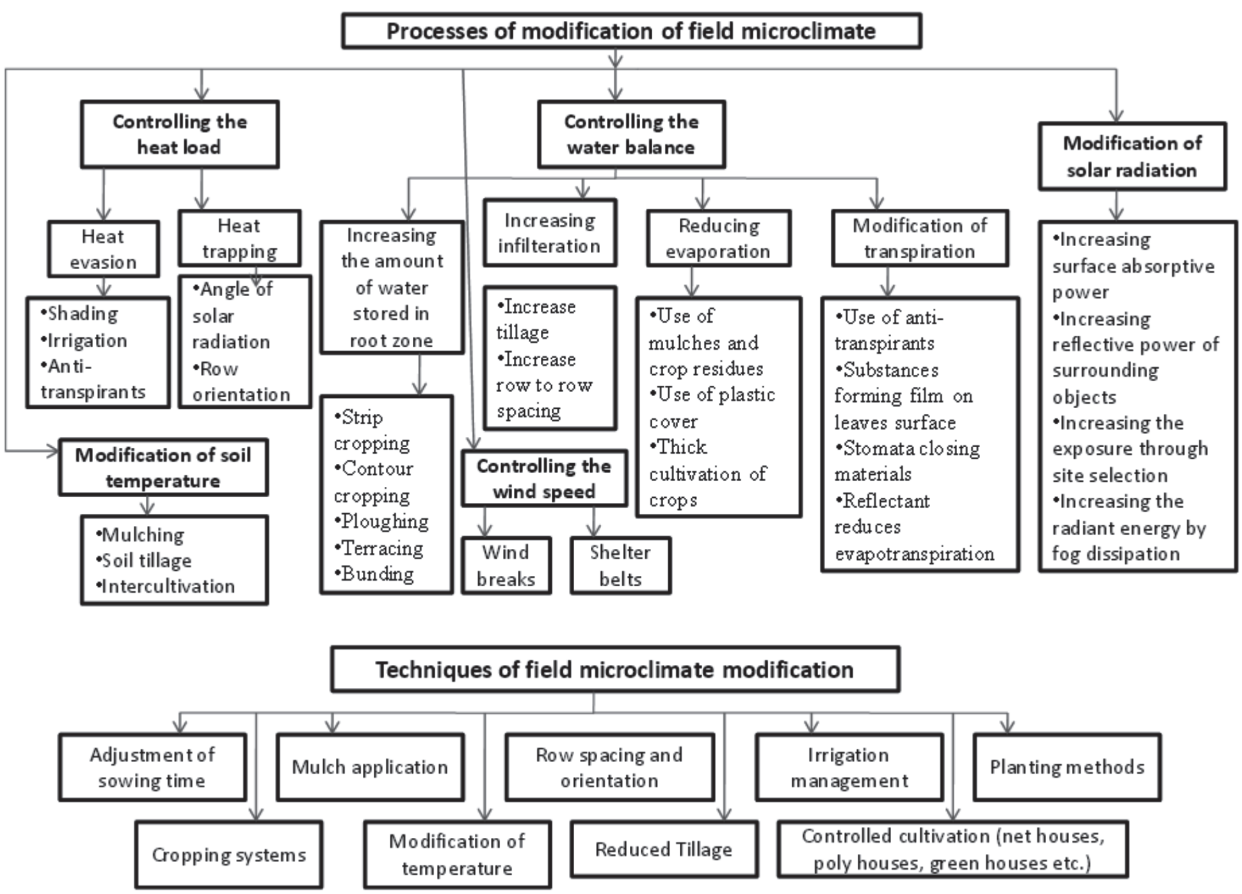


Fig. 1. Processes and techniques of field microclimate modification

Major techniques of field microclimate modifications

Different crops have specific climatic requirements at different growth stages. Thus, raising crops under favourable microclimate as per requirements of the crops, needs different management techniques so that sensitive growth stages of the crops can coincide with the favourable micro-environment. Various agronomic manipulations and other microclimate modification options viz. alteration in sowing time, mulch application, row orientation and spacing, irrigation management, planting methods, tillage practices, appropriate cropping systems and installation of the net houses/screen houses etc. can be used to make the crop microclimate optimum for highest growth rate and productivity.

Alteration in sowing time

Sowing time is an important production component that can be manipulated to counter the adverse effects of environmental stress. This is accomplished through shifting of sowing time so that any stress caused by environment is avoided during the critical stages of crop growth. Matching the phenology of the crop to the duration of favourable environmental conditions by selecting the most appropriate sowing time to avoid the periods of stress is crucial for obtaining maximum yields under changing climate (Singh *et al.,* 2016). Favorable microclimate can be created by modifying the date of sowing, which takes care of the deleterious effect of high temperature during reproductive growth period (Pal *et al.,* 1996). Temperature is one of the most important elements of climate which determines directly the potential productivity level particularly for winter crops. Light response i.e. photoperiodism, which not only control the temperature factor but also the vegetative growth as well as flowering of the plants, is important weather element for wheat crop to assess the thermal response and its requirement at different phenophases to harvest the potential yield (Singh *et al.,* 2008). For getting higher yield, sowing time of crops needs to be adjusted with suitable agroclimatic environment (Saha and Khan, 2008).

Terminal heat stress intensity is severe under late sown conditions in Punjab causing reduction in the duration of later growth phases and hence grain yield (Mavi and Tupper, 2005). Substantial increase in grain yield of wheat can be achieved by sowing the crop at the optimum time. Heat shock at the end of tillering strongly reduces the rate of leaf photosynthesis, while during grain filling it decreases both rate of photosynthesis and grain growth (Egli, 2004; Schapendonk *et al.,* 2007; Yang *et al.,* 2008). The grain yield of cereals has been reported to increase with increase in allocation to the reproductive organs with little increase in biological yield (Donald and Hamblin, 1976). It would be, therefore, appropriate that plants function in such a manner that maximum amount of dry matter goes to the spikes for increasing weight of grain during post anthesis period, leading to higher grain yield. Partitioning of dry matter at anthesis indicates the maximum contribution from stem, followed by roots, leaves and spikes, whereas at physiological maturity, the spikes contribute maximum, followed by roots, stem and leaves (Tyagi *et al.,* 2004). Date of sowing influences the yield considerably and delays in sowing subject the crop to mature early due to rise in temperature resulting in decreasing the number and size of grains (Parihar and Tripathi, 1989). Wheat being a thermosensitive crop, choice of suitable cultivar for different seeding time further gets prime importance.

Hundal *et al.* (2004) observed highest accumulated intercepted PAR and radiation use efficiency of mustard cultivars when sown in October, and lower when sown in September or November. Kingra *et al.* (2006) also observed higher dry matter, seed yield and heat use efficiency in earlier sown sunflower as compared to late sowing conditions. Kaur *et al.* (2014) observed higher canopy temperature in 15^{th} June transplanted rice crop followed by 30^{th} June, and the lowest in 15^{th} July transplanted crop under Punjab conditions. Kingra and Kaur (2013) observed decrease in dry matter, seed yield and heat use efficiency of Brassica sp. with delay in sowing. Akhter *et al.* (2015) also observed decrease in yield and yield attributing characters of brown sarson with delay in sowing from 1^{st} to

30th October. However, Pankaj *et al.* (2014) observed lowest heat use efficiency in October sown and highest in December sown barley cultivars. Thus, sowing time has a significant effect on heat and radiation use efficiency of crops and it can be adjusted to enhance the input use efficiency in crop production.

Mulch application

Mulch is a layer of material applied at the soil surface, which leads to conserve soil moisture, moderate soil thermal regime, reduce weed growth and improve fertility and soil health. Mohammad *et al.* (2012) observed significant increase in grain and straw yield of wheat when the crop residues were retained in the field than when they were removed. Iqbal *et al.* (2008) observed increase in water use efficiency of maize with increase in mulch amount from 2 to 6 Mg ha^{-1}. Yaseen *et al.* (2014) also observed increase in water use efficiency of maize with mulch application. Wang *et al.* (2011) reported increase in water use efficiency of maize under reduced tillage with residue incorporation. Similarly, Ram *et al.* (2012) observed increase in water use efficiency of maize under no tillage with mulch. Sarkar *et al.* (2007) observed effect of mulch type on moisture depletion rate and observed water-hyacinth mulch to be more effective than rice straw mulch by retaining more moisture in the soil profile. Mulching has potential to enhance soil quality over the long-term as well as increase in production. Crop residues placed on the soil surface shade the soil, serve as a water vapour barrier against evaporation losses, slow surface runoff, and increase infiltration (Mulumba and Lal, 2008). Mulching with crop residues improved water-use efficiency by 10-20% as a result of reduced soil evaporation and increased plant transpiration. In the case of winter wheat, straw mulching has been shown to increase water-use efficiency from 1.72 to 1.94 kg m^{-3} (Deng *et al*., 2006).

Mulch obstructs the solar radiation reaching the soil surface. They increase the soil temperature during winter and increase during summer season. White- and light-coloured materials which increase the reflectivity, are used to decrease soil temperature during summer season, whereas, dark-coloured materials and black plastic mulches are used to increase soil temperature during winter season. Straw mulches can be used during both the seasons as they increase soil temperature during winter season and decrease during summer season. Due to obstruction of the exchange of water vapours, mulches decrease the rate of evaporation from the soil and conserve soil moisture for use by the plants. Jalota *et al.* (2007) reported that straw mulch improves the crop productivity through optimizing the hydrothermal regimes of soil. The benefits are more in summer / *kharif* season and on soils having low retentivity. Kar and Kumar (2007) observed significantly higher leaf area index, intercepted photosynthetically active radiation, yield and water use efficiency of potato under mulch, which might be due to conservation of soil moisture and reduction of soil temperature by 4-6°C.

Hou *et al.* (2010) examined the effect of duration of plastic mulching on soil temperature, evapotranspiration, growth, yield and water use efficiency of potato under drip irrigation in an arid region of Northwest China. Daily mean soil temperature under the plastic mulch was 2-9 °C higher than under non-mulching conditions. The mulch effect on soil temperature was the greatest during the early growth and reduced as the plant canopy increased. Mulch reduced irrigation water required and evapotranspiration, however, extending mulch duration beyond 60 days had little effect on evapotranspiration. Both tuber yield and water use efficiency benefitted from early plastic mulching. Mulch cover for 60 days was found favourable for potato production campared to potatoes grown without mulch.

Row spacing and orientation

Row spacing has a great impact on canopy temperature and radiation interception by the crop. If row spacing is more, radiation interception by the crop decreases, more radiation falls on the soil surface and increases the soil temperature. On the other hand, if row spacing is less, radiation interception by the crop increases and its transmission towards soil surface decreases, which decreases the soil temperature. David *et al.* (2002) reported that plant architecture changes affect the canopy light environment, yield and yield components of narrow-row cotton. Alterations of canopy architecture that allow more light penetration into the lower depths of the canopy may be a way to increase the yield of cotton through greater boll production.

Appropriate row spacing and orientation help in trapping of radiation by the canopy, thus leading to higher radiation interception and crop productivity. Sandler *et al.* (2014) observed higher light interception with 19 cm row spacing in wheat as compared to that with 38 cm. Pathan *et al.* (2006) observed significantly higher light interception in wheat and barley along east-west row orientation as compared to north-south. Jha *et al.* (2012) reported significantly higher seasonal cumulated IPAR in east-west as compared to north-south oriented plots in mustard. Pandey *et al.* (2013) observed 11% higher grain of wheat in the north-south sowing as compared to the east-west sowing due to its significant effect on crop microclimate. Significantly higher light intensity was observed in north-south direction, whereas canopy temperature was significantly higher in east-west direction.

Irrigation management

By applying irrigation, soil moisture availability increases, which increases the evapotranspiration and decreases the soil as well as canopy temperature. Under very hot and dry conditions, light irrigation is a common practice to save crops from high temperature stress. Alberto *et al.* (2009) compared the CO_2 and heat fluxes in flooded and non-flooded rice fields in the Philippines to monitor the environment impact, in terms of carbon budget and heat exchange, of shifting from lowland rice production to aerobic rice cultivation as an alternative to maintain crop productivity under water scarcity. The aerobic rice fields had higher sensible heat flux (H) and lower latent heat flux (LE) compared to flooded fields. On seasonal average, aerobic rice fields had 48% more sensible heat flux while flooded rice fields had 20% more latent heat flux. Consequently, the aerobic rice fields had higher Bowen ratio (0.25) than flooded fields (0.14), indicating that a larger proportion of the available net radiation was used for sensible heat transfer or for warming the surrounding air. The total carbon budget integrated over the cropping period showed that the net ecosystem exchange (NEE) in flooded rice fields was about three times higher than in aerobic fields, while gross primary production (GPP) and ecosystem respiration (Re) were 1.5 and 1.2 times higher, respectively. The high GPP of flooded rice ecosystem was evident because the photosynthetic capacity of lowland rice is naturally large. The respiration (Re) of flooded rice fields was also relatively high because it was enhanced by the high photosynthetic activities of lowland rice as manifested by larger above ground plant biomass. The ratio of Re/GPP in flooded fields were 0.67 while it was 0.83 for aerobic rice fields (Alberto *et al.*, 2009).

Appropriate amount and time of irrigation results in managing heat and water stress and in improving yield and water use efficiency. Tesfaye *et al.* (2006) reported that radiation use efficiency was more sensitive to water stress at mid-season (MS) than late season (LS) stage in legumes. The reduction in radiation use efficiency during MS was 39, 30 and 29%, whereas during LS it was 18, 19 and 17% for beans, chickpea and cowpea, respectively. Quanqi *et al.* (2012) observed higher PAR capture ratio and radiation use efficiency with increase in irrigation application in maize. Kar and Kumar (2007) reported that increase in irrigations from one to four along with mulch application enhanced intercepted photo-synthetically active radiation in potato. Kingra *et al.* (2011) reported increase in yield and heat use efficiency of wheat with increase in irrigation application. Kingra *et al.* (2013) indicated that canopy temperature depression increased with increase in irrigation application. canopy-air-temperature difference values were positive for most of the growing period for the rainfed and negative for well-watered treatment for both the years. The rainfed treatments under both flat and bed planting methods experienced the highest Bowen ratio, whereas the well-watered treatments experienced the lowest Bowen ratio, indicating that much of the available energy was partitioned towards sensible heat under rainfed treatment and towards latent heat for well-watered treatment. Singh and Kingra (2015) observed highest water use efficiency of wheat sown during mid November with three post-sowing irrigations.

Planting methods

Method of planting also affects the crop microclimate due to its effect on soil properties. Fahong *et al.* (2004) observed that beds enhanced 10% yield of wheat due to improved soil physical condition as compared to flat sowing. Connor *et al.* (2003) noted water saving of 26-42% in beds as compared to flat sowing in various crops. Bed sowing produced significantly taller plants with greater biomass and grain yields probably due to better nutrient availability, good soil conditions and weed control in beds (Abdullah *et al.*, 2008; Shah *et al.*, 2013). Hezhong *et al* (2008) reported that furrow seeding improves the photosynthesis and dry matter production in cotton. Kaur *et al.* (2014) observed higher canopy temperature and PAR interception in bed planted rice as compared to conventional planting. Akbar *et al.* (2015) observed significantly higher leaf area index of cotton under bed and furrow method as compared to flat sowing with alternate row earthing up and flat sowing with drill. Singh *et al.* (2014) observed higher grain yield and water use efficiency of chick pea when planted on raised beds as compared to flat planting. Shah *et al.* (2015) observed highest yield and water use efficiency of maize when wheat straw mulch was used along with bed planting.

Tillage

Tillage is the physical manipulation of soil, which is intended to destroy weeds, incorporate crop residues and amendments into soil, increase infiltration and reduce evaporation, prepare seed bed and break hard layer to facilitate root penetration (Prihar and Jalota, 1990). Tillage practices modify the crop microclimate by affecting the soil properties. Tillage increase the porosity and decreases the thermal conductivity of the soil and increases the soil temperature. The upper loose soil surface also acts as a mulch and conserves soil moisture by decreasing evaporation losses. Pettigrew and Jones (2001) observed that conventionally tilled plants intercepted 28% more sunlight during pre-bloom and 17% more light at mid-bloom before both tillage treatments reached canopy closure in cotton. Lint yield was 11% lower in the no-tillage treatment than in conventional tillage due to 8% reduction in number of bolls m^{-2}.

Mohammad *et al.* (2012) observed comparable grain and straw yield of wheat with and without tillage. Whereas, Rabo and Ahmed (2013) observed significantly higher shelling percentage, 100 seed weight and pod yield of groundnut under zero tillage as compared to conventional tillage. Rashidi *et al.* (2010) recorded higher fruit weight, length, diameter and total soluble solids in tomato under no tillage. Noellemeyer *et al.* (2013) reported higher yield, soil available water content, consumptive water use and water productivity under no tillage in summer as well as winter crops. Sarkar *et al.* 2007 observed decrease in morning soil temperature by 0.1 to 0.4^{o}C and increase in yield of sarson by 25% under zero tillage as compared to conventional tillage. Malhi *et al.* (2006) reported significantly higher N_2O-N emissions under conventional tillage. Jalota *et al.* (2008) reported more remunerability of the cotton–wheat system with reduced tillage in cotton and minimum tillage in wheat as compared to conventional tillage. Chi *et al.* (2016) reported that no-till practices had lower total ecosystem respiration and evaporation, more net carbon uptake and a greater ratio of transpiration over evapotranspiration during the growing season.

Shelterbelts / Windbreaks

The main function of shelterbelts is to reduce the wind speed and cold advection. Due to reduction in wind speed, they decrease the evapotranspiration and increase the temperature and moisture. Windbreaks modify the micro-climate by providing the shelter, which reduces the wind speed and turbulence. Wind breaks protect the plants from the high intensity winds.

They modify the water table by reducing the water losses and hence they improve the crop productivity. Wind breaks also reduce the wind erosion. Cleugh (1998) reported that porous wind break modiofies airflow, microclimates and hence crop yields. In dry farming, windbreak reduces crop evapotranspiration by modifying the aerodynamic component of the energy balance (Burke, 1998). Campi *et al.* (2009) reported the positive effect of windbreaks in mitigating evapotranspiration, hence their significanrt applicability under dry-farming systems.

Cropping systems

Intercropping i.e. growing of two or more crops simultaneously on the same field such that the period of overlap is long enough to include the vegetative stage (Gomez and Gomez, 1983), has significant effect on microclimate and resource use efficiency (Gebru, 2015). Intercropping, double cropping and other mixed cropping practices lead to enhanced efficiency of farm resources with sustainable crop production (NRC, 1993; Tolera, 2003). Intercropping increases the radiation interception by the canopy and decreases its transmission towards th e soil surface, thus also decreasing the soil temperature. Improved productivity thus results from either greater interception of solar radiation or higher light use efficiency or their combination (Willey, 1990). Tsubo *et al.* (2001) reported more efficient radiation harvesting in intercropping of maize and beans as compared to sole crops. Pandey (2010) observed higher PAR interception and radiation use efficiency in maize and soybean intercropping as compared to sole maize crop. Farrel and Altieri (1995) elaborated that as a result of intercropping, microclimate within canopy can moderate temperature extremes, lower temperatures with reduced air movement leading to decreased evaporation rates and increased relative humidity, which is important in avoiding desiccation and providing favourable growth conditions even during the periods of moisture deficit. Wilson and Ludlow (1991) reported soil temperature upto 10°C cooler on forage under tree plantations in the tropics assisting seedling survival, soil water relations and possibly affecting the rate of litter breakdown and nitrogen mineralization. Although intercropping is also known to decrease the occurrence of weeds (Geno and Geno, 2001), insects and diseases (Pino *et al.*, 1994; Michael *et al.*, 1997), but modified microclimate especially moderate temperatures and increased relative humidity sometimes might become conducive for disease outbreak, especiaaly fugal pathogens (Gleissman, 1985).

Protected cultivation

Protected cultivation makes it possible to obtain increased crop productivity by maintaining a favourable environment for the plants (Kastoulas and Kittas, 2008). The use of netting and other type of covering has been shown to restrict air movement around the growing seedlings in higher temperature (Majumder, 2010; Nair and Nagouajio, 2010). Gogo *et al.* (2012) reported that netting effectively modified the microclimate around the growing tomato seedlings. There was an increase in daily temperature by about 3.5°C and increase in relative humidity by 10%. Elevated air temperatures inside the net along with improved moisture status and root development enhanced the uptake of nutrients such as potassium and nitrogen, thereby favouring leaf conductance and chlorophyll content. The net covering also offers a physical barrier reducing the occurrence of insect-pests. Licciardi *et al.* (2007) and Martin *et al.* (2006) observed delay in the infestation of cabbage by aphids under netting. Higher relative humidity recorded under netting could also affect the feeding habit of sucking pests, hence lowering their population under netting (Berlinger *et al.*, 2002). Leyva *et al.* (2015) concluded that fogging system could improve the climatic conditions under screenhouse and extend the growing season during adverse environmental conditions by moderating the extremes of microclimate during summer.

Conclusions

There have been predictions of rise in global average temperature, precipitation, carbon dioxide as well as extreme weather events by the end of

21st century. Microclimate modification techniques can prove effective adaptive strategies to manage extreme weather vulnerability and climatic risks in agriculture. Modification of physical environment, solar radiation, soil temperature, soil moisture and wind speed etc. by farm level adjustments and protected cultivation prove highly beneficial for better crop growth and yield performance. With delay in sowing, input use efficiency declines, but by adjusting the time of sowing crop yield and input use efficiency can be improved under changing climatic conditions. Mulching helps in regulating soil temperature and conserving soil moisture by preventing evaporation losses, hence saves the crop from harsh weather conditions. Row spacing and row orientation can be altered for efficient utilization of solar energy. Modified crop microclimate with improved irrigation management leads to increase heat and water use efficiency. Average daily temperature and relative humidity remain significantly higher in net house as compared to open conditions. Raised beds help in improving water use efficiency by saving irrigation water by 25-35%. Green house gas emissions reduce under no tillage treatment. Intercropping helps in improving PAR interception and RUE as compared to sole crop. The study concludes that intensity and frequency of extreme weather elements is likely to increase in future and microclimatic modifications can prove very effective adaptation measure to managing extreme weather vulnerability and climatic risks in crop production to ensure food security and sustainability of natural resources in future.

References

Abdullah, H.G., Khan, I.A., Khan, S.A. and Ali, H. 2008. Impact of planting methods and herbicides on weed biomass and some agronomic traits of maize, *Pakistan Journal of Weed Science Research* **14**: 121-130.

Aggarwal, P.K. 2008. Global climate change and Indian agriculture: impacts, adaptation and mitigation, *Indian Journal of Agricultural Sciences* **78**: 911-919.

Akbar, H.M., Akram, M., Hassan, M.W., Hussain, M., Rafay, M. and Ahmad, I. 2015. Growth, yield and water use efficiency of cotton (*Gossypium hirusutum* L.) sown under different planting techniques, Custus e @gronegocio on line – v. 11, n. 1 – Jan/Mar – 2015. www.custoseagronegocioonline.com.br.

Akhter, S., Singh, L., Rasool, R. and Ramzan, S. 2015. Effect of date of sowing and varieties on yield of brown sarson (*Brassica rapa* L.) under temperate Kashmir. *International Journal of Engineering Science Invention* **4**: 65-69.

Alberto, M.C.R., Wassmann, R., Hirano, T., Miyata, A., Kumar, A., Padre, A. and Amante, M. 2009. CO_2 / heat fluxes in rice fields: Comparative assessment of flooded and non-flooded fields in the Philippines, *Agricultural and Forest Meteorology* **149**: 1737-1750.

Alexandrov, V., Eitzinger, J., Cajic, V. and Oberforster, M. 2002. Potential impact of climate change on selected agricultural crops in north-eastern Austria, *Global Change Biology* **8**: 372-389.

Barlow, K.M., Christy, B.P., O'Leary, G.J., Riffkin, P.A. and Nuttall, J.G. 2015. Simulating the impact of extreme heat and frost events on wheat crop production: a review, *Field Crops Research* **171**: 109-119.

Berlinger, M.J., Taylor, R.A.J., Lebiush-Mordechi, S., Shalhevet, S. and Spharim, I. 2002. Efficiency of insect exclusion screens for preventing white fly transmission of tomato yellow leaf curl virus of tomatoes of Israel, *Bulltin of Entomology Research* **92**: 367-373.

Bishnoi, O.P. 2010. *Applied micrometeorology, applied climatology*, Oxford Book Company, Jaipur, India.

Burke, S. 1998. "Windbreaks", Inkate Press. p.129.

Campi, P., Palumbo, A.D. and Mastrorilli, M. 2009. Effects of tree windbreak on microclimate and wheat productivity in a Mediterranean environment, *European Journal of Agronomy* **30**: 220-227.

Chen, C.C. and McCarl, B.A. 2001. An investigation of the relationship between pesticide usage and climate change, *Climate Change* **50**: 475-487.

Chi, J., Waldo, S., Pressley, S., O'Keeffe, P., Huggins, D., Stockle, C., Pan, W.L., Brooks, E. and Lamb, B. 2016. Assessing carbon and water dynamics of no-till and conventional tillage cropping systems in the inland Pacific Northwest US using the eddy covariance method, *Agricultural and Forest Meteorology* **218-219**: 37-49.

Cleugh, H.A. 1998. Effect of windbreaks on airflow, microclimates and crop yields, *Agroforestry Systems* **41**: 55-84.

Connor, D.J., Gupta, R.K., Hobbs, P.R. and Sayre, K.D. 2003. Bed planting in rice-wheat system, In: *Addressing resource conservation issues in rice-wheat system of south-Asia: A resource book*. Rice-wheat Consortium for the Indo-gangetic plains. International maize and wheat improvement center, New Delhi, India, 103-108.

David, G., Reta-Sanchez and James, L.F. 2002. Canopy light environment and yield of narrow-row cotton as affected by canopy architecture, *Agronomy Journal* **94**: 1317-1323.

Deng, X.P., Shan, L., Zhang, H.P. and Turner, N.C. 2006. Improving agricultural water use efficiency in and semiarid areas of China, *Agricultural Water Management* **80**: 23-40.

Donald, C.M. and Hamblin, J. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria, *Advances in Agronomy* **26**: 361-404.

Egli, D.B. 2004. Seed- fill duration and yield of grain crops, *Advances in Agronomy* **83**: 243-79.

Eitzinger, J., Orlandini, S., Stefanski, R. and Naylor, R.E.L. 2010. Climate change and agriculture: introductory editorial, *Journal of Agricultural Science, Cambridge* **148**: 499-500.

Fahong, W., Xuqing, W. and Sayre, K. 2004. Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China, *Field Crops Research* **87**: 35-42.

Farrel, J.G. and Altieri, M.A. 1995. Agroforestry systems in agroecology, In: M A Altier (ed), *The Science of Sustainable Agriculture*. Intermediate Technology Publications, London. pp. 219-263.

Gangwar, B., Subash, N. and Ravisanker, N. 2016. Farming system approach to meet the challenges from extreme weather, *Mausam* **67**(1): 15-26.

Gebru, H. 2015. A review on the comparative advantages of inter-cropping to mono-cropping system, *Journal of Biology, Agriculture and Healthcare* **5**: 1-13.

Geno, L. and Geno, B. 2001. "Polyculture Production: Principles, benefits and risk of multiple cropping", A report for the Rural Industry Research and Development Corporation (RIRDC), Publication no. 01134.

Ghaffari, A., Cook, H.F. and Lee, H.C. 2002. Climate change and winter wheat management: a modeling scenario for south-eastern England, *Climate Change* **55**: 509-533.

Gleissman, S.R. 1985. *Agro-ecological Processes in Sustainable Agriculture*, Sleeping Bear Press, Chlesea, ML, USA.

Gogo, E.O., Saidi, M., Itulya, F.M., Martin, T. and Ngouajro, M. 2012. Microclimate modification using eco-friendly nets for high quality tomato transplant production by small scale farmers East Africa, *Horticultural Technology,* pp. 292-98.

Gomez, A.A. and Gomez, K.A. 1983. *Multiple cropping in the humid tropics of Asia*, Ottawa, 32p.

Hatfield, J.L. and Prueger, J.H. 2015. Temperature extremes: Effect on plant growth and development, *Weather and Climate Extremes,* **10**: 4-10.

Hezhong, D., Weijiang, L., Tang, W. and Zhang, D. 2008. Furrow seedling with plastic mulching increases stand establishment and lint yield of cotton in a saline field, *Agronomy Journal* **100**: 1640-1646.

Hou, X., Wang, F., Han, J., Kang, S. and Feng, S. 2010. Duration for plastic mulch for potato growth under drip irrigation in an arid region of Northwest China, *Agricultural and Forest Meteorology* **150**: 115-121.

Hundal, S.S., Kaur, P. and Malikpuri, S.D.S. 2004. Radiation use efficiency of mustard cultivars under different sowing dates, *Journal of Agrometeorology* **7**: 142-144.

IPCC 2007. Summary for Policymakers, In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

IPCC 2014. Climate change Impacts, adaptation and vulnerability, Working group II contribution to the fifth assessment report of the Inter-governmental Panel on Climate Change. Technical report. Cambridge University Press, Cambridge, UK/New York, USA.

Iqbal, M., Hassan, A.U. and Ibrahim, M. 2008. Effects of tillage systems and mulch on soil physical quality parameters and maize (*Zea mays* L.) yield in semi-arid Pakistan. *Biological Agriculture and Horticulture* **25**: 311-32.

Jalota, S.K., Buttar, G.S., Sood, A., Chahal, G.B.S., Ray, S.S. and Panigrahy, S. 2008. Effects of sowing date, tillage and residue management on productivity of cotton (*Gossypium hirsutum* L.) – wheat (*Triticum aestivum* L.) system in northwest India, *Soil and Tillage Research* **99**: 76-83.

Jalota, S.K., Khera, R., Arora, V.K. and Beri, V. 2007. Benefits of straw mulching in crop production: a review, *Journal of Research* **44**: 104-107.

Jha, S., Sehgal, V.K. and Subbarao, Y.V. 2012. Effect of direction of sowing and crop phenotype on radiation interception, use efficiency, growth and productivity of mustard, *Journal of Agricultural Physics* **12**: 37-43.

Kar, G. and Kumar, A. 2007. Effects of irrigation and straw mulch on water use and tuber yield of potato in eastern India, *Agricultural and Water Management* **94**: 109-116.

Katsoulas, N. and Kittas, C. 2008. Impact of greenhouse microclimate on plant growth and development with special reference to the solanaceae, *The European Journal of Plant Science and Biotechnology* **2** (Special Issue – 1): 31-44.

Kaur, A., Dhaliwal, L.K. and Singh, S. 2014. Microclimatic variations under different planting methods of rice, *Oryza sativa* L., *International Journal of Farm Sciences* **4**: 24-32.

Kingra, P.K. and Kaur, P. 2013. Agroclimatic study for prediction of growth and yield of Brassica sp. in central Punjab, *Journal of Agricultural Physics* **13**: 148-52.

Kingra, P.K., Kaur, P., Khera, M.K. and Hundal, S.S. 2006. Agroclimatic models for prediction of growth and yield of sunflower, *Helianthus annus* L., *Journal of Research Punjab agric Univ* **43**: 287-91.

Kingra, P.K., Mahey, R.K., Dhaliwal, L.K. and Singh, S. 2013. Impact of planting methods and irrigation levels on microclimate of wheat. *Journal of Agrometeorology,* **15**: 128-30.

Kingra, P.K., Mahey, R.K., Gill, K.K. and Singh, S. 2011. Thermal requirement and heat use efficiency of wheat under different irrigation levels in central Punjab, *Indian Journal of Ecology* **38**: 228-233.

Leyva, R., Aguilar, C.C., Rodrýguez, E.S., Gamez, M.R. and Soriano, T. 2015. Cooling systems in screenhouses: Effect on microclimate, productivity and plant response in a tomato crop, *Biosystems Engineering* **129**: 100-111.

Licciardi, S., Assogba-Komlan, F., Sidick, I., Chandre, F., Hougard, J.M. and Martin, T. 2007. A temporary tunnel screen as an ecofriendly method for small-scale farmers to protect cabbage crops in Benin, *International Journal of Tropical Insect Science* **27**: 152-158.

Mahi, G.S. and Kingra, P.K. 2013. *Comprehensive Agrometeorology,* Kalyani Publishers. pp 355.

Majumder, A. 2010. Large-scale net house for vegetable production: Pest management success and challenges for a new technology, Alabame Coop. Ext-System, Auburn Univ., Auburn AL.

Malhi, S.S., Lemke, R., Wang, Z.H. and Chhabra, B. S. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality and greenhouse gas emissions, *Soil and Tillage Research* **90**: 171-83.

Maliwal, P.L. 2011. *Agronomy at a glance*, pp. 337. S S S Printers, New Delhi.

Martin, T., Assogba-Komlan, F., Houndete, T., Hougard, J.M. and Chandre, F. 2006. Efficiency of mosquito netting for sustainable small holders, cabbage production in Africa, *Journal of Economic Entomology* **99**: 450-454.

Mavi, H. S. 1994. *Introduction to Agrometeorology*, Oxford and IBH Publishing Co., Pvt. Ltd., New Delhi.

Mavi, H.S. and Tupper, G.J. 2005. *Agrometeorology-Principles and Applications of Climate Studies in Agriculture*, p 48. The Haworth Press, Binghamton, New York.

Michael, V.V., Wang, J.F., Midmore, D.J. and Hartman, G.L. 1997. Effect of intercropping and soil amendment with urea and calcium oxide on the incidence of bacterial wilt of tomato and survival of soil borne *Pseudomonas solanacearum* in Taiwan", *Plant Pathology* **46**: 600-610.

Meehl, G.A., Stocker, T.F., Collins, W.D., Gaye, A.J., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, J.G., Weaver, A.J. and Zhao, Z. 2007. "Global Climate Projections", In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (Eds.), Cambridge University Press, Cambridge, U.K. and New York, NY.

Mishra, A. and Liu, S.C. 2014. Changes in precipitation pattern and risk of drought over India in the context of global warming, *Journal of Geophysical Research – Atmospheres* **119**: 7833-7841.

Mohammad, W., Shah, S.M., Shehzadi, S. and Shah, S.A. 2012. Effect of tillage, rotation and crop residue on wheat crop productivity, fertilizer nitrogen and water use efficiency and soil organic carbon status in dry area (rainfed) of north-west Pakistan, *Journal of Soil Science and Plant Nutrition* **12**: 715-727.

Mulumba, L.N. and Lal, R. 2008. Mulching effects on selected soil physical properties, *Soil and Tillage Research* **98**: 106-111.

Nair, A. and Ngouajio, M. 2010. Integrating row covers and soil amendments for organic cucumber production: Implications on crop growth, yield and microclimate, *Hortscience* **45**: 566-574.

National Research Committee (NRC), 1993. Sustainable agriculture and the environment in the humid tropics, National Academy Press, Washington D. C., 702p.

Noellemeyer, E., Fernández, R. and Quiroga, A. 2013. Crop and tillage effects on water productivity of dryland agriculture in Argentina, *Agriculture* **3**: 1-11.

Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvag, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J. and Micale, F. 2011. Impacts and adaptation of European crop production systems to climate change, *European Journal of Agronomy* **34**: 96-112.

Pal, S.K., Kaur, J., Thakur, R., Verma, U.N. and Singh, M.K. 1996. Effect of irrigation, seeding date and fertilizer on growth and yield of wheat (*Triticum aestivum* L.), *Indian Journal of Agronomy* **41**: 386-89.

Pandey, B.P., Basnet, K.B., Bhatta, M.R., Sah, S.K., Thapa, R.B. and Kandel, T.P. 2013. Effect of row spacing and direction of sowing on yield and yield attributing characters of wheat cultivated in Western Chitwan, Nepal, *Agricultural Sciences* **4**: 309-316. http://dx.doi.org/10.4236/as.2013.47044.

Pandey, V. 2010. *Agrometeorological services for farmers,* pp. 63-65. Krishna Printers, Ahmedabad.

Pankaj, S.C., Sharma, P.K. and Kingra, P.K. 2014. Thermal energy requirement and heat use efficiency of barley varieties under different dates of sowing, *Indian Journal of Ecology* **41**: 247-51.

Parihar, S.S. and Tripathi, R.S. 1989. Response of wheat to nitrogen, irrigation and sowing dates, *Indian Journal of Agricultural Sciences* **34**: 192-96.

Pathan, S., Hashem, A., Wilkins, N. and Borger, C. 2006. East-west crop row orientation improves wheat and barley grain yields, *Agribusiness Crop Updates* 2006.

Pettigrew, W.T. and Jones, M.A. 2001, Cotton growth under No-till production in the lower Mississippi river valley alluvial flood plain, *Agronomy Journal* **93**: 1398-1404.

Pino, M., Domini, M.E., Terry, E., Bertoli, M. and Espinos, R. 1994. Maize as a protective crop for tomato in conditions of environmental stress, *Cultivos Tropicales* **15**: 60-63.

Prihar, S.S. and Jalota, S.K. 1990, Bare soil evaporation in relation to tillage, *Advances in Soil Science* **12**: 187-216.

Quanqi, L., Yuhai, C., Xunbo, Z., Songlie, Y. and Changcheng, G. 2012. Effect of irrigation to winter wheat on the radiation use efficiency and yield of summer maize in double cropping system, *The Scientific World Journal* pp. 1-7.

Rabo, A.S. and Ahmed, H.G. 2013. Effect of tillage practices on the growth and yield of groundnuts (*Arachis hypogea*) at Dambatta, Kano, Nigeria", *International Journal of Scientific and Technology Research* **2**: 204-06.

Ram, H., Singh, Y., Saini, K.S., Kler, D.S., Timsina, J. and Humphreys, E.J. 2012. Agronomic and economic evaluation of permanent raised beds, no tillage and straw mulching for an irrigated maize-wheat system in northwest India. *Experimental Agriculture* **48**: 21-38.

Rao, V.U.M. and Rao, B. 2016. Coping strategies for extreme weather in dryland agriculture, *Mausam* **67**: 5-14.

Rashidi, M., Gholami, M. and Abbassi, S. 2010. Effect of different tillage methods on yield and yield components of tomato (*Lycopersicon esculentum*), *Journal of Agricultural and Biological Sciences* **5**: 26-30.

Saha, G. and Khan, S.A. 2008. Predicting yield and yield attributes of yellow sarson with agrometeorological parameters, *Journal of Agrometeorology* (Special issue – Part I): 115-119.

Sai, M.V.R.S., Murthy, C.S., Chadrasekar, K., Jeyaseelan, A.T., Diwakar, P.G. and Dadhwal, V.K. 2016. Agricultural drought: Assessment & monitoring, *Mausam* **67**: 131-142.

Sandler, L., Nelson, K.A. and Dudenhoeffer, C. 2014. Winter wheat row spacing and alternative crop effects on relay-intercrop, double-crop, and wheat yields, *International Journal of Agronomy* Volume 2015.

Sarkar, S., Paramanick, M. and Goswami, S.B. 2007. Soil temperature, water use and yield of yellow sarson (*Brassica napus* L. var. glauca) in relation to tillage intensity and mulch management under rainfed lowland ecosystem in eastern India, *Soil and Tillage Research* **93**: 94-101.

Schapendonk, A.H.C.M., Xu, H.Y., Van Der Putten, P.E.L. and Spiertz, J.H.J. 2007. Heatshock effects on photosynthesis and sinksource dynamics in wheat (*Triticum aestivum* L.). NJAS - Wageningen, *Journal of Life Sciences* **55**: 37-54.

Shah, S.S.H., Ahmad, S.B., Shah, S.H.H., Muhmood, A., Nawaz, A., Niaz, A.,Wakeel, A. and Majeed, A. 2015. Mulching effects on water productivity, maize yield and soil properties in bed and flat sowing methods, *Internationa Journal of Plant and Soil Science* **8**: 1-7.

Shah, S.S.H., Khan, A.H., Ghafoor, A., Bakhsh, A. 2013. Soil physical characteristics and yield of wheat and maize as affected by mulching materials and sowing methods, *Soil and Environment* **32**: 14-21.

Singh, L., Beg, M.K.A., Akhter, S., Qayoom, S., Lone, B.A., Singh, P. and Singh, P. 2014. Efficient techniques to increase water use efficiency under rainfed ecosystems, *Journal of Agricultural Research* **1**: 193-200.

Singh, S. and Kingra, P.K. 2015. Evapotranspiration and water productivity of wheat under different hydrothermal regimes, *Agricultural Research Journal* **52**: 48-53.

Singh, A.K., Tripathi, P. and Adhar, S. 2008. Heat unit requirements for phenophases of wheat genotypes as influenced by sowing dates, *Journal of Agrometeorology* **10**: 209-212.

Singh, K.K. and Kalra, N. 2016. Simulating impact of climatic variability and extreme climatic events on crop production, *Mausum* **67**: 113-130.

Singh, S., Kingra, P.K. and Singh, Som Pal, 2016. "Heat unit requirement and its utilisation efficiency in wheat under different hydrothermal environments, *Annals of Agricultural Research* New Series **37**: 1-11.

Tesfaye, K., Walker, S. and Tsubo, M. 2006. Radiation interception and radiation use efficiency of three grain legumes under water deficit conditions in a semi-arid environment, *European Journal of Agronomy* **25**: 60-70.

Tolera, A. 2003. Effects of nitrogen, phosphorous, farmyard manure and population of climbing bean on the performance of maize (*Zea mays* L.) / climbing bean (*Phaseolus vulgaris* L.) intercropping system in Alfisols of Bako. An M.Sc. Thesis Presented to the School of Graduate Studies of Alemaya University. 75p.

Trnka, M., Dubrovski, M., Semeradova, D. and Zalud, Z. 2004. Projections of uncertainties in climate change scenarios into expected winter wheat yields, *Theoretical and Applied Meteorology* **77**: 229-249.

Tsubo, M., Walker, S. and Mukhala, E. 2001. Comparisons of radiation use efficiency of mono-/inter cropping systems with different row orientations, *Field Crops Research* **71**: 17-29.

Tubiello, F.N., Donatelli, M., Rosenzweig, C. and Stockle, C. O. 2000. Effects of climate change and elevated CO_2 on cropping systems: Model predictions at two Italian locations, *European Journal of Agronomy* **12**: 179-89.

Tyagi, P.K., Pannu, R.K., Sharma, K.D., Chaudhary, B.D. and Singh, D.P. 2004. Post anthesis dry matter accumulation and its partitioning in different wheat (*Triticum aestivum*) genotypes under varying growing environments, *Indian Journal of Agronomy* **49**: 163-67.

Wang, X., Dai, K., Zhang, D. and Oenema, O. 2011. "Dryland maize yields and water use efficiency in response to tillage/crop stubble and nutrient management practices in China, *Field Crops Research* **120**: 47-57.

Willey, R.W. 1981. A scientific approach to intercropping research, In: Proc. International Workshop on Intercropping, International Crops Research Institute for the Semi-Arid Tropics. Andhra Pradesh, India.

Wilson, J.R. and Ludlow, M.M. 1991. The environment and potential growth of herbage under plantations, pp. 10-24. In: H. M. Shelter and W. W. Stur (eds.). Forages for Plantation Crops, Proceedings no. 32, June 1990, Australian Centre for International Agricultural Research, Bali.

Yang, W., Peng, S., Dionisio-Sese Rebecca, M.L., Laza, C. and Visperas, R.M. 2008. Grain filling duration, a crucial determinant of genotypic variation of grain yield in field grown tropical irrigated rice, *Field Crops Research* **105**: 221-27.

Yaseen, R., Shafi, J., Ahmad, W., Rana, M.S., Salim, M. and Qaisrani, S.A. 2014. Effect of deficit irrigation and mulch on soil physical properties, growth and yield of maize, *Environment and Ecological Research* **2**: 122-37.

Yashino, M.M. 1974. Agricultural Climatoloty in Japan, In: *Agricultural Meteorology of Japan*, Ed. Yoshiaki Mihara. Univ. of Tokyo Press: 19-21.

Received: February 28, 2017; Accepted: May 3, 2017