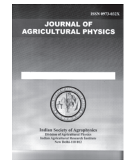
Vol. 23, No. 2, pp. 155-169 (2023)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in



Review Article

Climate Change Impacts and its Management in Maize-Wheat Cropping Systems through Agronomic Interventions - A Review

GURSEWAK SINGH[1], J.S. KANG[1], P.K. KINGRA[2]* AND JATINDER KAUR[2]

[1]Department of Agronomy, Punjab Agricultural University, Ludhiana-141004, Punjab
[2]Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana-141004, Punjab

ABSTRACT

Maize and wheat are nutrient exhaustive crops whose productivity is very susceptible to climate change driven weather parameters. Change in rainfall pattern and increase in the frequency and intensity of extreme weather events i.e. high/low temperatures, heat waves and cold waves decreases the crop productivity. As per the future prediction, the temperature may increase up to 2.5°C by 2050 and 2-3°C in the end of 21st century. The present review describe the impact of a rise and fall in temperature, solar radiation, and CO_2 on the productivity of maize and wheat cropping system. Agronomic management practices during the crop growth period of selecting crop cultivars, time of planting, plant population, dose, timing, and methods of application of in-puts are influenced by temperature, rainfall, solar radiation, and CO_2 concentration in the atmosphere. By changing the planting date, adopting new short-duration and early maturity varieties of maize and wheat are becoming significant under low-cost adoption technologies to mitigate climate change. Maize and wheat responds well to the higher levels of nutrients but no-till system frequently reveals suppressed yields because of less N availability due to slower soil N mineralization, greater immobilization, denitrification and NH_3 volatilization, mainly during the initial period of growing season as compared to conventional tillage systems. The review highlights the impact of heat stress and drought on soil processes, and overall soil health. The better performance of ridge-furrow systems could be due to proper drainage of excess water and adequate aeration during irrigation or heavy rainfall. If climate change continues to occur without any strategy adapted, then it projects a strong impact on crop productivity.

Key words: Climate change, Maize-Wheat cropping systems, Nitrogen scheduling, Tillage, Yield

Introduction

Maize (*Zea mays* L.), is an important cereal crop, with various uses. Maize, one of the most versatile emerging crops, has great adaptability in various agro-climatic conditions. Globally, maize, due to its higher genetic yield potential, is known as "The Queen of Cereals". It is one of the most versatile crops by nature; with flexibility indifferent agro-climatic conditions. Maize provides nutrients to humans and animals. Being C_4 crop, it has good yield potential and is the best substitute to overcome the risks associated with paddy cultivation including greenhouse gases mainly methane and nitrous oxide. Paddy cultivation also increases the outbreaks of pests (stem borer) and fungal diseases (false smut) and depleting the ground water level. Currently, it is grown over 170 countries, which produce nearly 1147.7 million MT of maize from 193.7 million ha with productivity of 5.75 t/ha (FAOSTAT, 2020). Maize is a crop, suitable for various soils ranging

*Corresponding author,
Email: pkkingra@pau.edu

from loamy sand to clay loam. Organic matter containing soil along with neutral pH is considered good for maize productivity.

Wheat (*Triticum aetivum* L.) is the broadly cultivated for foodcrop, in the world and ranks first amongst the cereals in terms of area and production. It is used in various forms by more than billion people around the world. In Punjab state, wheat is a dominant *rabi* season cereal crop. The normal sowing window is from the fourth week of October to the third week of November. However, in some parts of the state, late planting of the crop continues until mid-December. Wheat needs cool weather for early stages of growth. An unusual change in climatic parameters, particularly an increase in maximum/minimum temperatures above normal at any stage of crop growth, adversely affects growth and ultimately the potential yield of the crop.

In India, the area occupied by wheat was 31.45 million hectares, with a production of 107.59 million tonnes in 2019-20 (Anonymous, 2021). Climate change is a major challenge in the coming decades for sustainable agricultural production, especially by mid-century when global food demand is expected to be doubled. The results of different studies indicate that a reduction of food crops, under rainfed and irrigated conditions due to an increase in biotic stresses (of attack of pest, diseases and weeds etc.) induced by climatic change. However, increased climate variability in the recent past leads to large year-to-year fluctuations in crop production and threatens the sustainability of agriculture. Under such conditions, the adoption of resource conservation technologies is a dire need of human beings to manage the risk of climate change.

Climate Change impacts on Maize and Wheat

Maize

In an earlier study, Prabhjyot-Kaur and Hundal (2009) concluded that rise in temperature impact on maize crop in Ludhiana using CERES-Maize and indicated that grain yield decrease of 4.26, 0.02, 12.15, 10.99, 15.92 and 16.85% and advancement in maturity days by 1, 3, 3, 1, 2, and 2 days for a temperature increase from normal by 0.5, 1.0, 1.5, 2.5 and 3.0°C respectively. Later, Thornton *et al.* (2010) studied the effect of climate change in East Africa and found that maize yield would decrease by more than 5% under warm climate change scenario.

According to Wang *et al.* (2011) estimated decline in maize yield by 10-30% in the central plain and western regions of Jilin (China), while an increase in marginal areas of eastern countries during the years 2050-70 under conditions of climate change. These yield reductions in major areas are due to changes in rainfall and temperature, and predicted crop growing season will be shortened to 15-20 days by 2070. The marginal areas of eastern regions may show an increase in yield, but since this is not a major maize producing region, the overall fall in yields would be substantial for China in the coming decades. Similarly, a review and meta-analysis by Knox *et al.* (2012) show that projected change in maize yield is expected to be -5% across Africa. Later, Deb *et al.* (2015) reported that an raised CO_2 to be advantageous for maize yield, whereas higher temperatures at constant CO_2 level lead to in reduced yield.

Haris and Chhabra (2015) studied on the impact and adaptation for *kharif* maize in Bihar under different climate change scenarios and found the yield to decline under the predicted scenarios with the current management practices and inputs being used. Aversion of effect of rise in temperature and CO_2 is possible with agricultural practices like advanced sowing, one irrigation in rainfed crop and high dose of fertilizer. The study indicates that an advancement of 7 days showed a reduction in yield from baseline yield at Pusa during 2020 and 2050, for Patna only during 2080 and for Madhepur during 2020, 2050 and 2080. Combination of advanced sowing with a single irrigation will help Pusa and Madhepura during all of the future time periods while Patna will show reduction in decline of yield only with different combination of adaptation strategies. Best sowing time worked out were last week of April for the hybrids, first week of May for early composite variety and first week of May for local variety. Best N application schedule for all varieties was found to be 60+30 kg N ha^{-1}, 60 kg N ha^{-1} at sowing and 30 kg N ha^{-1} at knee high stage.

Bannayan *et al.* (2016) worked on the vulnerability of maize yield under climate change scenarios and found that the simulated yield showed a decline in maize yield from baseline over the future century at all locations in north-eastern Iran. The compared results showed that the yield would be reduced from -2.6% to -82%. The A2 scenarios reported the highest negative impact on maize yield and growth compared to B1, which showed more optimal yield conditions, which is due to more annual warming under A2 scenarios, as per the predictions.

Lin *et al.* (2017) simulated shortened maize growth duration and reduced maize yield at higher temperature. If the effects of CO_2 fertilization and adaptation measures to prevent the effect of CO_2 are not taken into account, then the projections for maize yield indicate a decrease on an average from 2.1 to 22.7% and from 6.3 to 47.5% from 2020s to 2080s under RCP 4.5 and RCP 8.5, respectively. The trend of continuous decline in the maize yield was seen for both RCP4.5 and RCP 8.5. Kaur (2016) used PRECIS model projected data for different locations in Punjab and revealed that CERES-Maize model under A1B, A2, and B2 scenarios predicted a significant decrease in crop duration from 19 to 25,12 to 21 and 7 to 16 days, respectively, by end century. A significant decrease in grain yield of 80-89%, 52-81% and 46-60% was also predicted for scenarios A1B, A2 and B2, respectively. The decreased crop duration might be the effect of high temperatures that are predicted for the end of the century and this reduced duration result in yield decrease under different scenarios.

The impact study of delayed sowing of maize (from September to December) on the quality of grain was carried out in the central temperate regions of Argentina using 18 commercial genotypes having different grain hardness (Abdala *et al.,* 2018). Late sown and early sown maize plants yield 11003 kg ha^{-1} and 12737 kg ha^{-1}, respectively, and later sown genotypes produced higher dry milling quality. Rainfall and distribution patterns affect maize biomass and yield. An increase in maize grain and biomass yield was observed after a decrease in rainfall by 10% and 20% from a baseline rainfall; however, an increase in rainfall by 30% from the baseline caused a decrease in grain yield (by 9%) and bio-mass (by 6%) (Srivastava, 2018). Three maize hybrids, i.e., FAO-290, FAO-350, and FAO-420 were investigated during 2011-2015 to know the effect of modeling emergence, silking, and sowing dates on the maturity of different hybrids (Szeles *et al.,* 2020).

Patidar *et al.* (2020) researched the potential impact of climate change on rainfed maize yield in central India. The grain yield saw a reduction by 8% at 1^{o}C rise in temperature for 30th June as the sowing date while advancement of sowing date beyond 30th June i.e. for 7th and 14th July saw a reduction in yield in the range from 7.5% to 7% from the normal. Adaptation of shift in sowing date from 7th to 14th July will assistance in reducing the temperature change impact on maize yield. Similar trend of maize yield reduction was found on increase in temperature by 2, 3 and 4^{o}C. The adverse effect of climate change on yield can be offset by delaying the sowing dates and shifting the water requirement in tune with the peak of seasonal rainfall as this would reduce the chances of exposure to drought during the silking-tasseling stage of the crop.

Maize yield and biomass are negatively affected by rising the temperature. The temperature rise of 1^{o}C from the base reduced the yield and biomass by 40% and 28%, respectively. Further, rising of 1^{o}C could reduce the yield by 10% and biomass by 8%. But the yield was increased with a 10% reduction in rainfall. However, a rainfall increase of 10% or a rainfall decrease of 20% would result in lower yields (Patidar *et al.,* 2020). Global Climate Models (GCMs) have reported an increase of 3.4^{o}C and 3.8^{o}C increase in maximum and minimum temperature for the period 2040-2049, respectively, and 29% decrease in future maize production (Ahmad *et al.,* 2020).

Wheat

Changes in temperature play a important role in determining crop productivity (Szeles *et al.,* 2020; Pramanik *et al*., 2018). Slightly changes in growing season temperature over the years appear to be the key aspect of weather affecting yearly wheat yield fluctuations (Fiscus *et al.,* 1997). Higher wheat yield under enhanced CO_2 and negligible change in temperature have been reported (Aggarwal *et al.,* 1993). Yield of cereals has been reported to decrease for different future scenarios (Peng *et al.,* 2004; Sinha *et al.,* 1991). Decline in potential yield of wheat and rice is linked to negative trend in solar radiation and an increase in minimum temperature in the Indo-Gangetic Plains of India (Pathak *et al.,* 2003). Differences in physiology of C_3 and C_4 plants make C_4 plants more efficient photo synthetically than C_3, especially when the level of $C0_2$ is high. Response of C_3 and C_4 crops to raised CO_2 levels when exposed frequently to water stress or changes in climatic factors such as temperature or rainfall may provide in consistent results because of the feedback between hydrology and nutrient relations (Deepak *et al.,* 2001).

Wheat production is severely affected by the temperature extremes due to climate change in many countries, and may reduce the crop yield by 6% for each 1°C rise in temperature (Peng *et al.,* 2004). Drought and high temperatures are the key stress factors with high impact on cereal yields (Rao and Sinha, 1994), and Rubisco, the central enzyme of photosynthesis, is disrupted if the temperature increases from 35°C, and stops the photosynthetic process (Sinha and Swaminathan, 1991). Due to climate change, water deficit and temperature extremes influence the reproductive phase of plant growth. It was showed that the flower initiation and inflorescence is badly affected by the water stress in cereals (Winkel *et al.,* 1997). Similarly, if the temperature increases of about 30°C during floret development it can cause sterility in cereals (Saini *et al.,* 1982). Drought stress influences wheat during all developmental stages, but grain formation and there productive stage are the most critical stages (Pradhan *et al.,* 2012). Wheat yield was decreased from 1% to 30% during the mild drought stress at post-anthesis while this reduction increased up to 92% in case of prolonged mild drought stress at flowering and grain formation (Araus *et al.,* 2002; De Oliveira *et al.,* 2013). Brown *et al.,* (2008) reported that wheat yield reduced by 10% with every 1°C increase in temperature. In another report it was discovered that a 3-4% reduction in wheat yield takes place for every 1°C increase in temperature (Ray *et al.,* 2015). Easterling *et al.* (2007) described that a 2°C increase in temperature cause 7% reduction in yield while a further increase in temperature to 4°C decreased the yield by up to 34% in wheat. In the year 2050, high temperatures and variations in rainfall resulted in a decrease in wheat yield by 22% in sub-Saharan Africa (Ringler *et al.,* 2010). The rainfall variations and disrupting rainy season has altered the national crop production by 90 to 95% (Kidane, 2010).

Dubey *et al.,* (2014) studied the impact of CO_2 and temperature on the yield, growth and physiology of wheat cultivars grown in the northwest plain of Uttarakhand and observed varieties PBW 343, HUM 234 and Raj 3765 to be the best performers w.r.t. growth and yield. In tropical regions of Iran, Andrazian *et al.* (2015) determined the sowing date of wheat using the CSM-CERES-Wheat model. The Wheat cultivars were sown on different dates, from 5 November to 9 January, and the results showed that the optimum sowing date of the cultivars differed from place to place. Kumar *et al.* (2014) used the Info Crop-wheat model to assess the vulnerability of wheat production in India to climate change. Simulation results revealed that climate change will reduce the wheat yield, ranging from 6 to 23% by 2050 and 15 to 25% by 2080. Late-sown areas suffered more than the timely-sown ones.

Srivastava *et al.,* (2021) projected results of maize yield for various representative concentration pathways (RCPs). For the time slice 2021-2050 and 2051-2080 the recorded change in yield was -10.58%, -14.80%, -21.02%, and -23.39% and -15.20%, -18.54%, -24.75%, and -26.83%, respectively for irrigated conditions. The record change in yield for rainfed conditions was higher for both the time slice 2021-50 and 2051-80 by 10.55%, 9.20%, 8.13%, and 7.47% and 10.63%, 6.65%, 7.47%, and 4.31%, respectively. Kaur and Hundal (2009) showed the advancement in maturity and reduced grain yield of maize due to increase in temperature.

Gill *et al.* (2014) depicted that wheat crop planted at Ludhiana acquired more days to reach physiological maturity and use heat more efficiently, resulting in more grain yield as compared to Bathinda. The results also showed that the cultivar PBW 621 was more efficient heat user as compared to the PBW 343 variety. Irrigation levels failed to produce difference in days required for initiation and completion of the various stages of crop growth.

Agronomic intervention – need of the hour

Some of the agronomic practices such as no-till (ZT), raised bed planting and residues management are found beneficial to preserve natural resources. The wheat under zero-till drill has been quickly increasing as it has greater rate of emergence and higher leaf area index (Yonglu *et al.,* 2000; Tripathi *et al.,* 2016). Malik *et al.* (2000) described that there was no major difference in ear length and effective tillers under zero and conventional tillage under the same nitrogen levels. Keeping in view, the changing climatic conditions and the dire need for resource conservation technologies like nitrogen scheduling, planting methods and tillage systems can be identified for maize-wheat cropping system.

Effect of Nitrogen scheduling on growth and yield attributes of maize and wheat system

Maize

Nitrogen is an integral part of many compounds essential for plant growth. Deficiency of nitrogen retards growth of plants and leads to low crop yields. Singh (2001) found that the maximum grain yield at 240 kg N ha^{-1}, which was significantly higher than 80 kg but statistically comparable with 160 kg ha^{-1} due to more cobs per hectare, grain row and cob length. Mkhabela *et al.* (2001) and Namakka *et al.* (2008) also observed similar results. Kumar (2008) studied the effect of planting density and nitrogen levels on sweet corn, in which increasing nitrogen levels were observed to progressively reduce the agronomic and physiological efficiency of nitrogen use. The results revealed that for the highest yield and net profitability, sweet corn should be grown with a fertilizer at 120 kg N ha^{-1}. Nitrogen application also improved nitrogen uptake with an increase of upto 120 kg ha^{-1}, which could be due to the higher nitrogen concentration and yield at higher level of nitrogen application. Singh (2010) found significantly higher grain yield @ 150 and 175 kg N ha^{-1} than @ 125 and 100 kg N ha^{-1} in maize. Kitchen *et al.* (2010) found average range of optimal nitrogen in alluvial, clay and loess soil types to be 153, 119 and 172 kg N ha^{-1} for, respectively.

Wheat

The most challenging task for the scientific community is to mitigate the threat posed to global food security caused due to climate change/ variability during the 21st century, while also maintaining the sustainability in agricultural systems. Fertilizer application at the right time using a suitable method in a balanced proportion showed a better impact on crop productivity. Nitrogen affects vegetative and quality yield, while phosphorus plays an essential role in metabolism and energy production reaction and can resist adverse environmental effects, leading to increased yield (Azink and Kajfez, 1983). Similarly, Bahera *et al.* (2000) described that at higher N levels, the sedimentation value and protein content increased and the percentage of yellow berries decreased. Sardana (2000) reported significant increase in wheat grain yield up to 160 kg N ha^{-1}. Nitrogen at 120 kg ha^{-1} increased mean grain yields by 32.5 percent over 80 kg N ha^{-1}.

Malik *et al.* (2001) reported that nitrogen levels (0, 35, 75, 100, 150 and 175 kg ha^{-1}) significantly affected yield and components of yield except germination count m^{-2}, and plant height. The highest grain yield was recorded with nitrogen application at the rate of 175 kg ha^{-1}. Nehra *et al.* (2001) reported that the application of increasing levels of nitrogen through fertilizers improved dry matter accumulation, effective 5 tiller number, grains per ear, grain and straw yields, photosynthetic pigments and photosynthesis pointedly over no-fertilizer treatment in wheat. Saren and Jana (2001) observed that in wheat crop, nitrogen resulted a significant increase in all yield attributes.

Patil and Itnal (2002) studied that increasing the N application rate from 50 to 100 kg ha^{-1} increased protein content from 13.73 to 14.10% in the wheat crop. Further increasing N to 150 kg ha^{-1} did not significantly increase grain protein (14.25%). Sharma *et al.* (2002) reported the response of wheat *(Triticum aestivum)* to nitrogen and sulfur and its residual effect on pearl millet *(Pennisetum glauccum)*. Uppal *et al.* (2002) reported a significant effect of four levels of N (120, 160, 200 and 240 kg ha^{-1}) and observed that increasing N level increased grain hardness, protein content, beta-carotene content and sedimentation value. Kumaw and Rathore (2003) also reported a significant increase in growth and yield of wheat with nitrogen application up to 120 kg ha^{-1} except thousand grain weight.

In wheat, its deficiency reduces the number of tillers and leaf area by producing smaller and fever leaves (Sato and Oyanagi, 2006). Application of phosphorus fertilizer through the appropriate method at optimum amount and duration is the main factor in increasing agricultural production and its sustainability (Rehman *et al.,* 2006). Hussain *et al.* (2008) reported gradual increase in wheat grain yield with increase in P_2O_5 from 60 to 120 kg ha^{-1}. Kaleem *et al.* (2009) reported that the highest dose helped in achieving the highest test weight which subsequently ameliorates to attain maximum wheat productivity (35.57 q ha^{-1}). Similar results were found by Khan *et al.* (2007) that treatment given 90 kg P_2O_5 ha^{-1} resulted in significantly higher grain yield and gave an increase of 22% over the control. Khan *et al.* (2008) studied the mutual influence of nitrogen and phosphorus levels in wheat and observed highest wheat yield @ 180 kg N and 90 kg P_2O_5 ha^{-1} and the minimum found in control. Brennan and Bolland (2009) reported significant increase in protein content of wheat with increase in N application, but K had no significant effect on protein content. Ghamry *et al.* (2009) reported that maximum grain yield (53.1 q ha^{-1}) found with FYM whereas the minimum (52.8 q ha^{-1}) found with control application. Likewise, Bandyopadhay *et al.* (2010) investigated the effect of integrated use of FYM and chemical fertilizer on soybean productivity. They reported that application of FYM (4 t ha^{-1}) along with recommended NPK significantly improved the grain yield of soybean by 14.2% over NPK and 50.3% over the control treatment. Ooro *et al.* (2011) reported significant increase in the protein content of wheat flour and the nitrogen of the grain at higher nitrogen rate. Conventry *et al.* (2011) reported significant effect of FYM on grain yield. Addition of FYM with the recommended NPK resulted in significantly higher grain yield (54.2 q ha^{-1}) while (49.5 q ha^{-1}) was only found with the recommended NPK. Asif *et al.* (2012) also concluded that nitrogen has a significant impact on the number of fertile tillers. They reported a significantly more number of fertile tillers m^{-2} (358.8) with150 kg N ha^{-1} than with 75 kg N ha^{-1}. Nitrogen has significantly influenced the content of starch and protein in wheat crop. Gluten constituted major seed storage protein as its content was comparatively higher when applying 90 kg N ha^{-1} followed by 120 kg N ha^{-1}.

Haile *et al.* (2012) revealed that 120 kg N ha^{-1} resulted in significantly higher protein content in wheat grains than 90 kg N ha^{-1}. Ma *et al.* (2013) observed that when six rates of K (Potash) were applied (15, 22.5, 30, 45, 75, 135 kg ha^{-1}) in wheat and 135 kg K ha^{-1} it indicated significantly increase in K use efficiency, tiller development, shoot dry weight, leaf photosynthesis and seed yield. Rakshit *et al.* (2015) investigated the effect of optimal (100% NPK) to super-optimal doses (200% NPK) in wheat and reported a higher grain yield (55 q ha^{-1}) with 200% NPK content than with 100% NPK application (29.2 q ha^{-1}). It was concluded that the highest grain yield can be obtained with the application of NPK (150:90:60 kg ha^{-1}). The use of organic manures and crop residue retention are recommended as the best soil management practices in intensive wheat farming systems (Singh *et al.*, 2005). The optimal use of fertilizers might come from matching the nutrient supply with the crop demand and fertilizer losses can be large when application is not synchronized with crop growth and development. Now days, a soil management strategy depends mainly on inorganic chemical-based fertilizers, which poses a serious threat to human health and the environment (Bhardwaj *et al.,* 2014). However, to meet "food grain needs" it is indispensable to enhance wheat yield by higher N (nitrogen) and suitable genotypes (Tripathi *et al.,* 2016).

Zhana *et al.* (2016) obtained 19% higher grain yield of wheat without the application of K. Tripathi *et al.* (2016) reported significant increase in wheat grain yield with the application of farmyard manure (FYM) with highest yield of 57.4 q ha^{-1} from 100% NPK with FYM followed by 56.3 q ha^{-1} with 100% NPK application. FYM at the rate of 10 ton ha^{-1} incorporated 30 days before sowing had delayed phenology and increased crop productivity in wheat crop. Besides the yield, FYM also increases soil water holding capacity and improves infiltration rate (Noreen and Noreen, 2012). Yadav and Dhanai (2017) contemplated the impact of various measurements of nitrogen (100, 120 and 140 kg

ha^{-1}) on different character and wheat yield and found that nitrogen application at 140 kg N ha^{-1} was the best for accomplishing the most astounding characteristics of expression such as plants tallness, dry weight, spike length, the number of spikes/ear, the number of seed per spike, 1000-grain weight and grain yield (40.5 q ha^{-1}).

Xu *et al.* (2017) studied the promotion of potassium allocation to the stem improves the bending resistance of maize stalks. They concluded that application of K significantly increased the diameter of the internodes, which ultimately enhancing stalks lodging resistance. Aatif *et al.* (2017) investigated the effect of phosphorus levels and farmyard manure on wheat yield and yield components. FYM (9 t ha^{-1}) resulted in the highest spike length, grains per spike and grain yield (46.91 q ha^{-1}) while the minimum (33.0 q ha^{-1}) was recorded in plots treated without FYM. Tedone *et al.* (2018) revealed the favouable effect of N @ 90 kg ha^{-1} with split application at three stages of wheat viz. sowing, tillering and stem elongation on grain yield, quality and nitrogen agronomic efficiency (NAE) with less environmental impact. Wang *et al.* (2018) also observed higher grain yield and water use efficiency under higher N application.

Effect of tillage and planting method on growth and yield of maize and wheat system

Tillage is as old as agriculture. Tillage has several purposes, the most important of which is proper seedbed preparation and weed control.

Maize

Numerous studies have shown the beneficial effect of tillage practice with retention of crop residues on the soil surface on maize yield (Triplett *et al.,* 1968; Lal, 1974, 1978, 1995; Unger, 1986; Wicks *et al.,* 1994). Sharma (1991) reported 25-31% higher grain yield in maize sown in furrows with 15 cm high ridges than flat beds. Joshi and Dastane (1966) also reported benefits of ridge planting than flat planting in sandy loam soil. Debebe (1999) observed better performance of ridge sown *kharif* maize under excess water conditions in sandy loam at Ludhiana than flat planting. A negative yield response of corn to no tillage was also reported by Chen *et al.* (2011). Ramakrichenin *et al.* (2002) observed that ridge and furrow planting technique registered the highest values of growth traits and thus resulted in higher grain yield. Kumar (2008) reported that ridge sown *kharif* maize produced significantly higher maize yield and yield attributes than that on flat beds.

Wheat

Zero tillage or no tillage helps in reducing the losses by advancing wheat sowing by 10-15 days and also saves time and costs associated with field preparation (Pal *et al.,* 1996). Yadav *et al.* (2002) reported higher no. of grains/spike and spike density of wheat planted on raised beds than conventionally sown wheat on a flat surface. Su *et al.* (2007) also described that wheat yield significantly affected by tillage methods. Zero-tillage planting of wheat also permits for band application of basal fertilizer which confirms placement of phosphate fertilizers directly in the planting area and also saves 25% in seeding rate to achieve sufficient plant support as compared to traditional broadcasting. Planting wheat with zero tillage saves time and energy, while a significant amount of these valuable resources are spent preparing the land for growing wheat (Dhillion *et al.,* 2005).

In many agricultural regions it can reduce or eliminate soil erosion and also increase the amount and variety of life in and on the soil. Zero tillage has been found to improve yield attributes in comparison to conventional tillage (Mishra *et al.,* 2011). It has been reported that the adoption of zero tillage in cereal cropping systems in the IGP advances the sowing time (Erenstein *et al.,* 2012), which also increases the thermal window for wheat, thus proves helpful to escape terminal heat effect. Although ZT in rice and wheat resulted in slightly lower rice yield, but it significantly improved wheat yield, which increased the overall system productivity by 0.63 Mg ha^{-1} $year^{-1}$ (Jat *et al.,* 2014). Ozpinar (2015) also reported significant differences in stem and leaf biomass between tillage systems. However, Sirazuddin *et al.* (2019) reported that residue retention did not influence grain yield of wheat.

Table 1. Highest maize yield (t/ha) obtained from different nitrogen schedule in different regions

Nitrogen (kg/ha)	0	30	40	50	60	100	150	160	180	200	220
Parbati Adhikari *et al.* (2016), Nepal	2.80	3.91	3.51	-	3.81	-	-	-	-	-	-
Leila Hejazi and Ali Soleymani (2014), Isfahan	2.77	-	-	2.84	-	3.62	3.59	-	-	-	-
Kripa Adhikari *et al.* (2021), Nepal	-	-	-	-	-	-	-	7.25	8.94	9.61	10.07

Table 2. Highest wheat yield (t/ha) obtained from different nitrogen schedule in different regions

Nitrogen (kg/ha)	0	40	50	60	80	90	100	120	150	180
Verma *et al.* (2005), Kanpur, U.P.	-	-	-	4.3	-	4.6	-	4.8	-	-
Kachroo and Ravinder (2006), Kashmir	-	3.5	-	-	5.1	-	-	5.3	-	-
Kumar *et al.* (2007) Hisar, Haryana	-	-	-	-	-	3.9	-	4.2	4.3	4.3
Singh *et al.* (2009), Ludhiana, Punjab	6.5	-	-	-	-	6.6	-	6.8	7.1	-
Singh *et al.* (2010), Kasmir	-	-	4.4	-	-	-	4.7	-	4.7	-

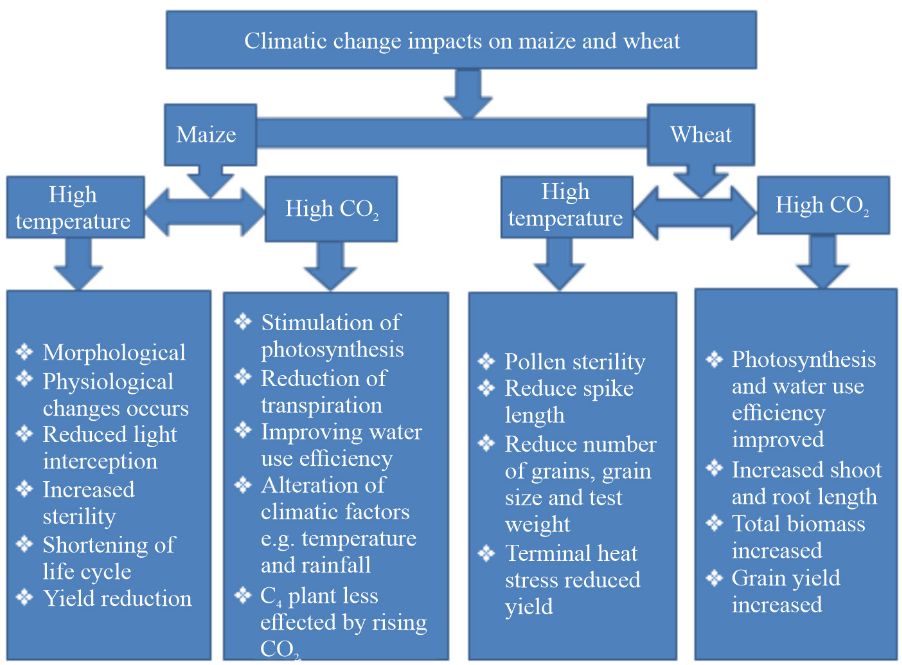


Fig. 1. Impact of Climate change on maize and wheat

Interactive effect of tillage, planting methods and nitrogen application on growth and productivity of Maize-Wheat systems

Phillips (1980) showed that when nitrogen fertilizer was applied to well-drained soil, corn grain yield was higher in no-till systems than conventional tillage, but when no fertilizer was applied, maize yield was higher with conventional tillage. Blevins (1983) reported that at low nitrogen fertilization rates the average 10-year corn yield was higher for conventional tillage than no-till, but at moderate to high nitrogen fertilization rates, it was equal or higher for no-tillage. Leaf area and dry matter accumulation were highest in crops planted in beds. An increase in nitrogen level produced leaves per plant; higher LAI

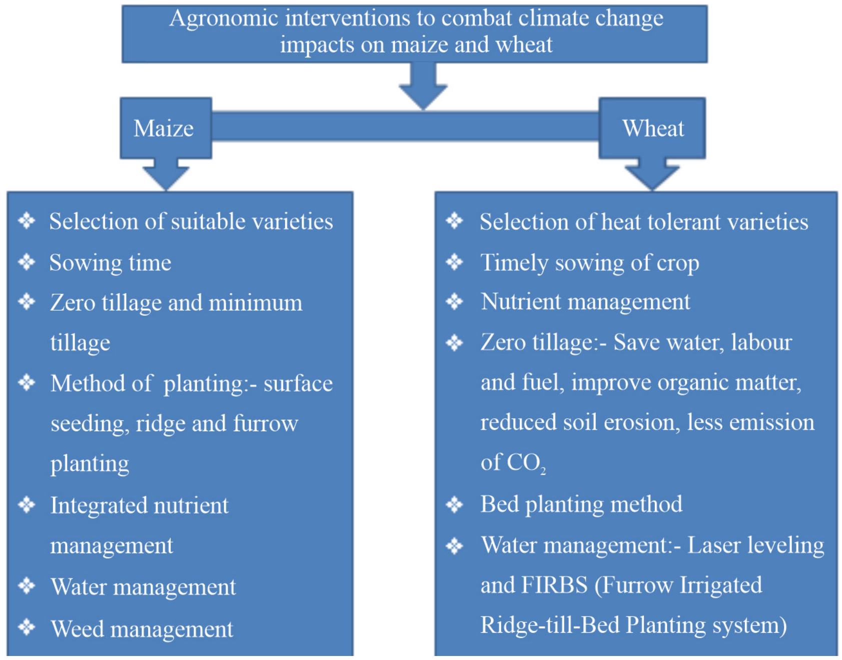


Fig. 2. Agronomic interventions to combat Climate change impact on maize and wheat

resulted in higher dry matter accumulation. An increase in leaf area with an increase in nitrogen level is attributed to better crop growth with greater nitrogen availability, as reported by Vedivel *et al.* (2001). No tillage was also found to produce relatively higher grain yield, however, there was no effect of P on grain yield. An important advantage of bed planting in the field is flexibility in applying fertilizer when and where it can be used effectively, as reported by Sayer (2003). Fahong *et al.* (2004) showed that raised beds improve nitrogen use efficiency by 10% in China. In recent years, wheat has often been delayed resulting in yield losses due to terminal heat stress (Kaur and Pannu, 2008; Sharma *et al.,* 2007). However, delayed sowing also increased nutrient content in grain and straw, whereas it decreased nutrient uptake (Kumar *et al.,* 1998).

Conclusions

From a review of the above studies, it maybe concluded that nitrogen is an essential nutrient known to enhance the growth and productivity of the maize and wheat. As climate change is likely to have adverse impacts on growth and productivity of the maize-wheat systems, thus the combination of tillage, planting methods and nitrogen fertilization offers the opportunity for increasing production. The results introduced from studies have indicated reduced yield of Maize-Wheat in future, so there is dire need to introduce management strategies to stabilize the maize and wheat yield in India and Punjab state. Different mitigation/adaptation measures viz. alteration in sowing time, planting methods, tillage practices like bed planting, zero tillage and Nitrogen scheduling can be adapted to get stable yields of Wheat-Maize. Thus, still a gap exists, that be studied for different nutrients under various environmental conditions and with levels of soil exploitation under different tillage interventions.

References

Aatif, M., Khan, H., Anjum, M.M., Ali, N. and Hamid, M. 2017. Effect of farm yard manure and phosphorus levels on yield and yield components of wheat. *International Journal of Environmental Science and Technology* **2**: 1-5.

Adhikari, K., Bhandari, S., Aryal, K., Mahato, M. and Shrestha, J. 2021. Effect of different levels of nitrogen on growth and yield of hybrid maize (*Zea mays* L.) varieties. *Journal of Agriculture and Natural Resources* **4**: 48-62.

Adhikari, P., Baral, B.R. and Shrestha, J. 2016. Maize response to time of nitrogen application and planting seasons. *Journal of Maize Research and Development* **2**: 83-93.

Aggarwal, P.K. and Sinha, S.K. 1993. Effect of probable increase in carbon dioxide and temperature on productivity of wheat in India. *Journal of Agricultural Meteorology* **48**: 811-814.

Ahmad, I., Ahmad, B., Boote, K. and Hoogenboom, G. 2020. Adaptation strategies for maize production under climate change for semi-arid environments. *European Journal of Agronomy* **115**: 126040.

Andarzian, B., Hoogenboom, G., Bannayan, M., Shirali, M. and Andarzian, B. 2015. Determining an optimum sowing date of wheat using CSM-CERES-Wheat model. *Journal of the Saudi Society of Agricultural Sciences* **14**: 189-199.

Anonymous 2021. https://www.indiabudget.gov.in/economicsurvey/doc/Statistical-Appendix-in English.pdf.

Araus, J., Slafer, G., Reynolds, M. and Royo, C. 2002. Plant breeding and drought in C_3 cereals: What should we breed for? *Annals of Botany* **89**: 925-940.

Asif, M., Maqsood, M., Ali, A., Hassan, S.W., Ahmad, S. and Javed, M.A. 2012. Growth, yield components and harvest index of wheat (*Triticum aestivum* L.) affected by different irrigation regimes and nitrogen management strategy. *Science International* **24**: 215-218.

Azink, M. and Kafez, L. 1983. A nine year fertilizer experiment on maize, Kmetystov. *Field Crop Research* **39**: 7-21.

Bahera, U.K., Chougule, B.A., Thakur, R.S., Ruwali, K.N., Bhawsar, R.C. and Pandey, H.N. 2000. Influence of planting dates and nitrogen levels on yield and quality of durum wheat (*Triticum durum*). *Indian Journal of Agricultural Science* **70**: 434-436.

Bandyopadhay, K.K., Misra, A.K., Ghosh, P.K. and Hati. 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil and Tillage Research* **110**: 115-125.

Bannayan, M., Paymard, P. and Ashraf, B. 2016. Vulnerability of maize production under future climate change: possible adaptation strategies. *Journal of the Science of Food and Agriculture* **96**: 4465-4474.

Bhardwaj, D., Ansari, M.W., Sahoo, R.K. and Tuteja, N. 2014. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories* **13**: 1-10.

Blevins, R.L. 1983. Long term tillage and nitrogen fertilization effect on soil properties of an Alfisoil under corn/cotton production. Dept. of soil and crop Science Texas A and M University.

Brennan, R.F. and Bolland, M.D.A. 2009. Comparing the nitrogen and potassium requirements of canola and wheat for yield and grain quality. *Journal of Plant Nutrition* **32**: 2008-2026.

Brown, L.R. and Plan, B. 2008. Mobilizing to Save Civilization (Substantially Revised); WW Norton & Company: New York, NY, USA, 2008.

Chen, Y., Liu, S., Li, H., Li, X. F., Song, C. Y., Cruse, R.M. and Zhang, X.Y. 2011. Effects of conservation tillage on corn and soybean yield in the humid continent climate region of Northeast China. *Soil and Tillage Research* **115**: 56-61.

Conventry, D.R., Poswal, R.S., Yadav, A., Gupta, R.K., Gill, S.C., Chhokar, R.S., Kumar, V., Sharma, R.K., Kumar, A., Mehta, A., Kleemam, S.G.L. and Cummins, J.A. 2011. Effect of tillage and nutrient management on wheat productivity and quality in Haryana, India. *Field Crop Research* **123**: 234-40.

D.A.C. 2020. Annual report Department of Agriculture Cooperation and Farmers' Welfare, 2019-20. Ministry of Agriculture and Farmers' Welfare Government of India, New Delhi, *www.agricoop.nic.in.*

De Oliveira, E.D., Bramley, H., Siddique, K.H., Henty, S., Berger, J. and Palta, J.A. 2013. Can elevated CO_2 combined with high temperature ameliorate the effect of terminal drought in wheat? *Functional Plant Biology* **40**: 160-171.

Deb, P., Kiem, A. S., Babel, M.S., Chu, S.T. and Chakma, B. 2015. Evaluation of climate change impacts and adaptation strategies for maize cultivation in the Himalayan foothills of India. *Journal of Water and Climate Change* **6**: 596-612.

Deb, P., Kiem, A.S., Babel, M.S., Chu, S.T. and Chakma, B. 2015. Evaluation of climate change impacts and adaptation strategies for maize cultivation in the Himalayan foothills of India. *Journal of Water and Climate Change* **6**: 596-612.

Debebe, G.D. 1999. *Evaluation and mitigation of yield losses caused by flooding in maize.* M.Sc. Thesis, Department of Agronomy, Punjab Agricultural University, Ludhiana, India.

Deepak, S.S. and Aggarwal, M. 2001. Influence of elevated CO_2 on the sensitivity of two soybean cultivars to sulphur dioxide. *Environmental and Experimental Botany* **46**: 81-91.

Dhillon, S.S., Prashar, A. and Thaman, S. 2005. Comparative studies on the effect of weed management practices on *Phalaris minor* Retz. in bed and conventionally planted wheat (*Triticum aestivum* L.). *Indian Journal of Ecology* **32**: 72-75.

Dubey, S.K., Tripathy, S.K., Pranuthy, G. and Yadav, R. 2014. Impact of projected climate change on wheat varieties in Uttrakhand, India. *Journal of Agricultural Meteorology* **16**: 26-37.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Erenstein, O., Sayre, K., Wall, P., Helin, J. and Dixon, J. 2012. Conservation agriculture in maize and wheat-based systems in the (sub) tropics: Lessons from adaptation initiatives in South Asia, Mexico, and Southern Africa. *Journal of Sustainable Agriculture* **36**: 180-206.

Fahong, W., Xuging, W. and Sayer, K.D. 2004. Comparison of conventional, flood irrigated, flat planted with furrow irrigated raised bed planting for winter wheat in China. *Field Crop Research* **87**: 35-42.

FAOSTAT. 2020. Statistical database Food and Agricultural Organisation of the United Nations 2020.

Fiscus, E.L., Reid, C.D., Miller, J.E. and Heagle, A.S. 1997. Elevated CO_2 reduces O_3 flux and O_3 -induced yield losses in soybeans: possible implications for elevated CO_2 studies. *Journal of Experimental Botany* **48**: 307-313.

Ghamry, A.M., Hamid, A.M. and Mosa, A.A. 2009. Effect of farmyard manure and foliar application of micronutrients on yield characteristics of wheat grown on salt affected soil. *American-Eurasian Journal of Agricultural and Environmental Science* **5**: 460-465.

Gill, K.K., Babuta, R.K., Kaur, N., Prabhjyot-Kaur and Sandhu, S.S. 2014. Thermal requirement of wheat crop in different agroclimatic regions of Punjab under climate change scenarios. *Mausam* **65**: 417-424.

Haile, D., Nigussie, D. and Ayana, A. 2012. Nitrogen use efficiency of bread wheat. *Journal of Soil Science and Plant Nutrition* **12**: 389-410.

Haris, A.A. and Chhabra, V. 2015. Studies on Maize Potential in Bihar under Climate Change Scenario: Impact and Adaptation. *Journal of AgriSearch* **2**: 40-43.

Hussain, N., Khan, M.B. and Ahmad, R. 2008. Influence of phosphorus application and sowing time on performance of wheat in calcareous soils. *International Journal of Agriculture and Biology* **10**: 399-404.

Jat, R.K., Sapkota, T.B., Singh, R.G., Jat, M.L., Kumar, M. and Gupta, R.K. 2014. Seven years of conservation agriculture in a rice-wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research* **164**: 99-210.

Joshi, M.S. and Dastane, N.G. 1966. Studies in excess water tolerance of crop plants II Effect of different durations of flooding at different stages of growth, under different lay outs on growth, yield and quality of maize. *Indian Journal of Agronomy* **11**: 70-79.

Kachroo, D. and Ravinder, R. 2006. Growth, nutrient uptake and yield uptake as influenced by biofertilizers and nitrogen. *Indian Journal of Agronomy* **51**: 37-39.

Kaleem, S., Ansar, M., Ali, M.A., Sher, A., Ahmad, S., Ahmad, G. and Rashid, M. 2009. Effect of phosphorus on the yield and yield components of wheat under rainfed conditions. *Sarhad Journal of Agriculture* **25**: 21-24.

Kaur, A. and Pannu, R.K. 2008. Effect of sowing time and nitrogen schedules on phenology, yield and thermal-use efficiency of wheat (*Triticum aestivum*). *The Indian Journal of Agricultural Sciences* **78**: 366-369.

Kaur, N. 2016. Simulating the yield of maize (*Zea mays* L.) under projected climate change scenarios in Punjab, Ph.D. dissertation, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, India.

Khan, M.U., Qasim, M. and Khan, I.U. 2007. Effect of integrated nutrient management on crop yields in rice-wheat cropping system. *Sarhad Journal of Agriculture* **23**: 1019-1020.

Khan, P., Imtiaz, M., Aslam, M., Shah, S.K.H., Nizamuddin, M., Menon, M.X. and Siddiqui, S.H. 2008. Effect of different nitrogen and phosphorus rates on the performance of wheat. *Sarhad Journal of Agriculture* **24**: 233-240.

Kidane, G. 2010. Agricultural based livelihood systems in drylands in the context of climate change. Inventory of adaptation practices and technologies of Ethiopia, Ethiopian Institute of Agricultural Research in collaboration with Environmental Sustainability pp. 112.

Kitchen, N.R., Sudduth, K.A., Drummond, S.T. and Vories, E.D. 2010. Ground-based canopy reflectance sensing for variable rate nitrogen corn fertilization. *Agronomy Journal* **102**: 71-84.

Knox, J., Hess, T., Daccache, A. and Wheeler, T. 2012. Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters* **7**: 34-32.

Kumar, A. 2008. Growth, yield and water use efficiency of different maize (*Zea maize*) based cropping systems under varying planting methods and irrigation levels. *Indian Journal of Agricultural Science* **78**: 244-247.

Kumar, A. 2008. Production potential and nitrogen use efficiency of sweet corn as influenced by different planting densities and nitrogen levels. *The Indian Journal of Agricultural Sciences* **79**: 351-355.

Kumar, R., Aggarwal, S.K. and Nanwal, R.K. 2007. Effect of planting systems, seed rates and nitrogen levels on bread wheat *(Triticum aestivum*). *The Indian Journal of Agricultural Sciences* **77**: 669-671.

Kumar, S.N., Aggarwal, P.K., Rani, D.N.S., Saxena, R., Chauhan, N. and Jain, S. 2014. Vulne*rabi*lity of wheat production to climate change in India. *Climate Research* **59**: 173-187.

Kumar, S., Bangarwa, A.S., Singh, D.P. and Phogat, S.B. 1998. Dry matter accumulation in dwarf wheat varieties under different nitrogen levels and sowing dates. *Journal of Research* **28**: 151-157.

Kumawat, B.S. and Rathore, S.S. 2003. Effect of preceding grain legumes on growth, yield, nutrient content and uptake by wheat (*Triticum aestivum*) under different nitrogen levels. *Crop Research Hisar* **25**: 209-214.

Lal, R. 1974. Soil temperature, soil moisture and maize yield from mulched with rice straw and unmulched tropical soil. *Plant and Soil* **40**: 92-93.

Lal, R. 1978. Influence of within and between row mulching on soil temperature, soil moisture, root development and yield of maize (*Zea mays* L.) in tropical soils. *Field Crops Research* **1**: 127-139.

Lal, R. 1995. Tillage and mulching effects on maize yield for seventeen consecutive seasons on a tropical alfisol. *Journal of Sustainable Agriculture* **5**: 79-93.

Leila, H. and Ali, S. 2014. Effect of different amounts of nitrogen fertilizer on grain yield of forage corn cultivars in Isfahan. *International Journal of Advanced Biological and Biomedical Research* **2**: 608-614.

Lin, Y., Feng, Z., Wu, W., Yang, Y., Zhou, Y. and Xu, C. 2017. Potential, Impacts of Climate Change and Adaptation on Maize in Northeast China. *Agronomy Journal* **109**: 1476-1490.

Ma, Q., Scanlan, C., Bell, R. and Brennan, R. 2013. The dynamics of potassium uptake and use, leaf gas exchange and root growth throughout plant phenological development and its effects on seed yield in wheat (*Triticum aestivum*) on a low-K sandy soil. *Plant and Soil* **373**: 373-384.

Malik, R.K., Yadav, A., Banga, R.S. and Singh, S. 2000. Zero-till wheat sowing and alternate herbicides against resistant *Phalaris minor* in rice-wheat cropping system. *Indian Journal of Weed Science* **47**: 233-39.

Mehta, S., Bedi, S. and Vashist, K.K. 2010. Performance of winter maize (*Zea mays*) hybrid to planting methods and nitrogen levels. *The Indian Journal of Agricultural Sciences* **81**: 50-54.

Mishra, S.K., Tripathi, D.K., Srivastava, N.K., Beg, M.Z. and Singh, C. 2011. Effect of different level of nitrogen on Wheat after rice under Zero tillage. *The Indian Journal of Agricultural Sciences* **2**: 97-100.

Mkhabela, M.S. and Shikhulu, J.P. 2001. Response of maize cultivar to different levels of nitrogen application in Swaziland, *Seventh Eastern and Southern Africa Regional Maize Conference*, pp. 377-381.

Namakka, A., Abubakar, I.U., Sadik, I.A., Sharifai, A.I. and Hassas, A.H. 2008. Effect of sowing date and nitrogen level on yield and yield components of two extra early maize varieties (*Zea mays*) in Sudan Savanna of Nigeria. *Journal of Agriculture and Applied Biology* **3**: 57-68.

Nehra, S., AjitHooda, I.S. and Singh, K.P. 2001. Effect of integrated nutrient management on growth and yield, of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **46**: 112-117.

Noonari, S., Kalhoro, S.A., Ali, A., Mahar, A., Raza, S., Ahmed, M., Shah, S.F.A. and Baloch. 2016. Effect of different levels of phosphorus and method of application on the growth and yield of wheat. *Indian Journal of Natural Sciences* **8**: 305-314.

Noreen, F. and Noreen, S. 2012. Effect of different fertilizers on yield of wheat. *International Journal of Scientific Research* **3**: 1596-1599.

Ozpinar, S. and Ozpinar, A. 2015. Tillage effects on soil properties and maize productivity in western Turkey. *Archives of Agronomy and Soil Science* **61**: 1029-1040.

Pal, S.K., Kaur, J., Thakur, R., Verma, V.N. and Singh, M.K. 1996. Effect of irrigation, seeding rate and fertilizer on growth and yield of wheat (*Triticum aestivum* L.). *Indian Journal of Agronomy* **41**: 386-389.

Pathak, H., Bhatia, A., Jain, N. and Aggarwal, P.K. 2003. Climatic potential and on farm yield trends of rice and wheat in the lndo-Gangetic Plains. *Field Crops Research* **80**: 223-234.

Patidar, R., Mohanty, M., Nishant, K., Gupta, S.C., Somasundaram, J., Chaudhary, R.S., Soliya, R., Hati, K.M., Prabhakar, M., Reddy, K.S., Patra, A.K. and Srinivas, R.C. 2020. Potential impact of future climate change on maize (*Zea mays* L.) under rainfed condition in central India. *Journal of Agrometeorology* **22**: 18-23.

Patil, R.H. and Itnal, C.J. 2002. Nitrogen uptake and gran protein in emmer wheat genotypes as influenced by sowing dates and nitrogen levels. *Karnataka Journal of Agricultural Sciences* **15**: 349-52.

Phillips. 1980. Effect of tillage on rainfed maize and soybean yield and the nitrogen fertilizer requirements for maize. Department of Primary industry and Fisheries, Australia.

Peng, S., Huang, J., Sheehy, J.E., Laza, M.R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. and Cassman, K. 2004. Rice yields decline with higher night temperature from global warming. *Agricultural Sciences* **101**: 9971-9975.

Prabhjyot-Kaur and Hundal, S. 2009. Production potential of cereal crops in relation to climate changes under Punjab conditions. *Journal of Agrometeorology* **11**: 18-23.

Pradhan, G.P., Prasad, P.V., Fritz, A.K., Kirkham, M.B. and Gill, B.S. 2012. Effects of drought and high temperature stress on synthetic hexaploid wheat. *Functional Plant Biology* **39**: 190-198.

Pramanik, P., Chakrabarti, B., Bhatia, A. *et al*. 2018. Effect of elevated temperature on soil hydrothermal regimes and growth of wheat crop. *Environmental Monitoring and Assessment* **190**: 217. https://doi.org/10.1007/s10661-018-6576-8

Rakshit, R., Patra, A.K., Purakayastha, T.J., Singh, R.D., Pathak, H. and Dhar, S. 2015. Effect of super-optimal doses of NPK fertilizers on nutrient harvest index, uptake and soil fertility levels in wheat crop, under maize (*Zea mays* L.) - wheat (*Triticum aestivum* L.) cropping system. *International Journal of Bio-resource and Stress Management* **6**: 15-23.

Ramakrichenin, B., Sakthivel, N. and Balasubramanian, A. 2002. Effect of pre-monsoon sowing and land management practices on growth, yield parameters and yield of rainfed maize. *Madras Agricultural Journal* **89**: 177-179.

Rao, G.D. and Sinha, S.K. (994. Impact of climate change on simulated wheat production in India. In *Implication of Climale Change for International Agriculture: Crop Modeling Study* (eds Rosenzweig, C. and Iglesias, I.), USEPA 230-B-94-003, USEPA, Washington DC, USA, Ray, D.K., Gerber, J.S., MacDonald, G.K. and West, P.C. 2015. Climate variation explains a third of global crop yield variability. *Nature Communications* **6**: 5989.

Rehman, O., Zaka, M.A., Rafa, H.U. and Hassan, N.M. 2006. Effect of balanced fertilization on yield and phosphorus uptake in wheat-rice rotation. *Journal of Agricultural Research* **10**: 140-148.

Ringler, C., Zhu, T., Cai, X., Koo, J. and Wang, D. 2010. Climate Change Impacts on Food Security in Sub -Saharan Africa. IPFPRI.

Saini, H and Aspinall, D. 1982. Abnormal sporogenesis in wheat (*Triticum aestivum* L.) induced by short periods of high temperature. *Annals of Botany* **49**: 835-846.

Sardana, V. 2000. Effect of nitrogen application on grain yield and incidence of grain mottling of durum wheat (*Triticum durum*). *Indian Journal of Agronomy* **45**: 711-716.

Saren, B.K. and Jana, P.K. 2001. Effect of depth of irrigation and level and time of nitrogen application on growth, yield and nutrient uptake by wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **46**: 227-232.

Sato, A. and Oyanagi, M.W. 2006. Effect of phosphorus content on the emergence of tillers in wheat cultivars. *Japan Agricultural Research* **1**: 27-30.

Sayre, K.D. 2003. Raised-bed cultivation, In: Rattan Lal (ed.) *Encyclopedia of Soil Science pp* 14. Taylor and Francis.

Sharma, K.D., Pannu, R.K. and Behl, R.K. 2007. Effect of early and terminal heat stress on biomass partitioning, chlorophyll stability and yield of different wheat genotypes *Proc: The international conference on sustainable crop production in stress environment: Management and genetic options.* Pp 187-94. *Agrobios* (International), Jodhpur.

Sharma, S.N., Kumar, T., Kumar, V., Singh, R.G. and Sharma, R.B. 2002. Effect of integrated nutrient management on transplanted rice and its residual effect on succeeding wheat crop, in rain-fed low lands. *Indian Journal of Agronomy* **4**: 311-317.

Singh, N.P. 2001. Fertilizer management in Maize. *Indian Farming Digest* pp: 32-34.

Singh, P., Singh, K.N., Singh, R., Aga, F.A., Bahar, F. and Raja, W. 2010. Evaluation of wheat (*Triticum aestivum*) cultivars for productivity and economics under grade levels of nitrogen in temperate Kashmir. *Indian The Journal of Agricultural Science* **80**: 380-384.

Singh, Y.P., Singh, R. and Gautam, A.K. 2009. Effect of nitrogen levels on yield and nutrient uptake by salt tolerant rice and wheat cultivars in Gypsum amended sodic soils. *Journal of the Indian Society of Soil Science* **56**: 86-91

Singh, Y., Singh, B. and Timsna, J. 2005. Crop, residue management for nutrient cycling and improving soil productivity in rice-based cropping system in the tropics. *Advances in Agronomy* **85**: 269-407.

Sinha, S.K. and Swaminathan, M.S. 1991. Deforestation, climate change and sustainable nutrients security. *Climate Change* **16**: 33-45.

Sirazuddin, Singh, V.P., Chandra, S., Singh, S.P., Guru, S.K., Pareek, N., Sarvadamana, A.K. and Paliwal, A. 2019. Growth and Productivity of Wheat under Tillage Systems and Residue Loads in Tarai Region of Uttarakhand, *India. International Journal of Current Microbiology and Applied Sciences* **8**: 11-19.

Soussana, J.F. and Schmidhuber. 2007. J. Food, fibre and forest products. *Climate Change* **273**: 313.

Srivastava, R.K., Panda, R.K. and Chakraborty, A. 2021. Assessment of climate change impact on maize yield and yield attributes under different climate change scenarios in eastern India. *Ecological Indicators* **120**: 1068812.

Su, Z., Zhang, J., Wu, W., Cai, D., Lv, J., Jiang, G., Huang, J., Gao, J., Hartmann, R. and Gabriels, D. 2007. Effects of conservation tillage practices on winter wheat water-use efficiency and crop, yield on the Loess Plateau, China. *Agricultural Water Management* **87**: 307-314.

Szeles, A. and Huzsvai, L. 2020. Modelling the effect of sowing date on the emergence, silking and yield of maize (*Zea mays L.*) in a moderately warm and dry production area. *Agronomy Research* **18**: 579-94.

Tedone, L., Ali, S.A., Verdini, L. and Mastro, G.D. 2018. Nitrogen management strategy for optimizing agronomic and environmental performance of rainfed durum wheat under the Mediterranean climate. *Journal of Cleaner Production* **172**: 2058-2074.

Thornton, P.K., Jones, P.G., Alagarswamy, G., Andresen, J. and Herrero, M. 2010. Adapting to climate change: agricultural system and household impacts in East Africa. *Agricultural Systems* **103**: 73-82.

Tripathi, S.C., Chander, S. and Meena, R.P. 2016. Maximizing wheat yield through integrated use of farmyard manure and fertilizers. *SAARC Journal of Agriculture* **14**: 103-111.

Triplett, Jr. G.B., Van Doren, Jr. D.M. and Schmidt, B.L. 1968. Effect of corn (*Zea mays* L.) Stover mulch on no tillage corn yield and water infiltration. *Agronomy Journal* **90**: 447-454.

Unger, P.W. 1986. Wheat residue management effects on soil water storage and corn production. *Soil Science Society of America* **50**: 764-770.

Uppal, R.S., Singh, R.P. and Singh, J. 2002. Effect of nitrogen level and time of application of quality of durum wheat. *Crop Improvement* **29**: 58-64.

Vedivel, N., Subhian, P. and Velayutham, A. 2001. Effect of integrated nitrogen-management practices on the growth and yield of rainfed winter maize (*Zea mays* L.). *Indian Journal of Agronomy* **46**: 250-254.

Verma, C.P., Prasad, K. and Verma, R.N. 2005. Production potential, and economics of maize-wheat cropping system under different soil conditioners and fertility levels. *Crop Research* **29**: 23-27.

Wang, L., Palta, J.A., Chen, W., Chen, Y. and Deng, X. 2018. Nitrogen fertilization improved water-use efficiency or winter wheat through increasing water use during vegetative rather than grain filling. *Field Crop Research* **197**: 41-53.

Wang, P., Sun, R., Zhang, J., Zhou, Y., Xie, D. and Zhu, Q. 2011. Yield estimation of winter wheat in the North China plain using the remote-sensing-photosynthesis-yield estimation for crops (RS-P- YEC) model. *International Journal of Remote Sensing* **32**: 6335-6348.

Wicks, G.A., Crutchfield, D.A. and Burnside, O.C. 1994. Influence of wheat (*Triticum aestivum*) straw mulch and metolachlor on corn (*Zea mays* L.) growth and yield. *Weed Science* **42**: 141-147.

Winkel, T., Renno, J.F. and Payne, W. 1997. Effect of the timing of water deficit on growth, phenology and yield of pearl millet (*Pennisetum glaucum* (L.) R. Br.) grown in Sahelian conditions. *Journal of Experimental Botany* **48**: 1001-1009.

Xu, Z., Lai, T., Li, S., Si, D., Zhang, C., Cui, Z. and Chen, X. 2017. Promoting potassium allocation to stalks enhances stalks bending resistance of maize (*Zea mays* L.). *Field Crops Research* **215**: 200-206.

Yadav, A., Malik, R.K., Chauhan, B.S., Kumar, V., Banga, P.S., Singh, S., Yadav, J.S., Punia, S.S., Rathee, S.S. and Sayre, K.D. 2002. Feasibility of raising wheat on furrow irrigated raised beds in south-western Haryana", *Proc. International Symposium on Herbicide Resistance Management and Zero Tillage in rice-wheat Cropping System, March 4-6, CCS Haryana Agricultural University, Hisar, India. pp* 201-06.

Yadav, M.S. and Dhanai, C.S. 2017. Effect of different doses of nitrogen and seed rate on various characters and seed yield of wheat. *Journal of Pharmacognosy and Phytochemistry* **6**: 01-5.

Yonglu, T., Gang, H., Tao, Y. and Lixum, Y. 2000. High yielding cultivation techniques for wheat under the rice-wheat cropping system in the Sichuan province of China *pp* 11-23 in *Soil and crop management practices for enhanced productivity of the rice-wheat cropping system in the Sichuan province of China.* RWC paper series 9, New Delhi Eds

Zhana, A., Zoua, C., Ye, Y., Liuc, Z., Cui, Z. and Chen, X. 2016. Estimating on-farm wheat yield response to potassium and potassium uptake requirement in China. *Field Crops Research* **19**: 13-19.

Received: 6 June 2023; Accepted: 11 September 2023