EFFECT OF CLIMATE CHANGE ON PRODUCTIVITY OF RICE AND WHEAT IN TARAI AND BHABAR AGRO-CLIMATIC ZONE OF UTTARAKHAND

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Abstract-The rice-wheat cropping system is a very important and popular cropping system being followed in the tarai area of Uttarakhand. The area, characterized by shallow water table and moist soil regime, lies within a narrow east-west strip of 8 to 25 km wide, on an outwash plain, gently slopping (<1%) southwards below the Bhabar tract along the foot hills of the Himalayas. The entire area is dissected by a number of small streams originating as springs from the junctions of Bhabar and tarai belts. In India, about 10.0 million hectare area is under rice-wheat cropping system and of this a large portion (4.8 m ha) falls in the tarai area of Uttarakhand. The sowing of wheat after rice is being followed since about more than five decades after bringing the area under crop cultivation since its deforestation in 1950. In rice-wheat cropping system a complete recommended set of agronomic practices is followed including timely control of pests and diseases, proper integrated nutrient management, application of balanced fertilizers and crop residue management, recommended tillage practices after harvesting of rice and control of weed flora over a time period under different conditions and crop stages. In-spites of these the yield of wheat after rice in the area has declined by about 20-30 % after the green revolution. It was thought that this decline in tend may follow the change in climatic conditions specially the air temperature and the rainfall in the area.

Crop productivity can be affected by climate change in two ways, one directly due to changes in the climatic variable mainly temperature and precipitation and indirectly through changes in soil, distribution and frequency of infestation by insects, diseases or weeds. In the present investigation, the productivity and sustainability of rice-wheat cropping system has been evaluated by analyzing the impacts of temperature and rainfall over past 45 years on yields of rice and wheat recorded at G.B.Pant University of Agriculture & Technology, Pantnagar (29o N latitude, 79o 30'E longitude and altitude 243.84 m amsl) located in tarai and bhabar agroclimatic zone of Uttarakhand. The rice yields for 45 kharif seasons from 1961 to 2005 and wheat yields from rabi seasons of 1961-62 to 2005-06 was collected from the Pantnagar University Farm. The maximum and minimum temperatures as well as rainfall data of the same duration were collected from meteorological observatory situated within the University Campus. Five year averages of the yields and climatic variables were worked out from 1961 to 2005 and then the changes in yields and rainfall and temperature change trends were calculated and finally, the simple regression equation of the type as well as curvilinear regression analysis (Ezekiel and Fox, 1959) were employed to develop regression equations between yields of Rice and Wheat with changes in climatic variables using statistical programs.

The following curvilinear regression equation for change in yield of rice as a function of change in rainfall and maximum, minimum and mean air temperatures during the kharif season was developed:

$$Y = 6.344 - 1.02 X_1 + 3.45 X_2 - 0.0157 X_3 - 4.073 X_4, \quad R^2 = 0.712$$

This shows that in this area about 71.2 % variations in rice yields are due to variations in south-west monsoon rainfall and temperatures. However, for wheat in rabi season, following regression equation between change in wheat yield and climatic variables was obtained

$$Y = 12.767 - 1.080 X_1 + 0.261 X_2 + 1.917 X_3 + 1.632 X_4, \quad R^2 = 0.924$$

This indicates shows that in this area about 92.4 % variations in wheat yields are due to variations in winter rainfall and temperatures.

Results of this studies showed that there has been a gradual increase in mean seasonal air temperature by 0.4 oC and rainfall variability is with 10 to 30 % during kharif season (from June to October) over last 45 years at tarai & bhabar agroclimatic- zone of Uttarakhand. There have been changes in rice yields. However, the yields of rice has been found to increase over the years due to introduction of high yielding varieties and adoption of improved cultivation technology and irrigation facilities in last two decades. Data also showed that the years in which rainfall is very high, the rice yields are low due to more incidences of diseases in crop in the area. Results of analysis for rabi season from 1961-62 to 2005-06 over last 45 years showed that the mean seasonal air temperature during Rabi season (from November to April) has also increased by 0.4 oC and rainfall variability is within 8 to 40 %. However, the wheat yields have also been found to change depending upon the rainfall distribution and rainfall variability except some variations. Results also indicate that in years in which winter rainfall was excessive, and then wheat yields were found to decline due to lodging and insect problems and in years of low winter rains, there has been response of irrigation in maximizing wheat production in the area. It has also been observed that in years in which mean monthly air temperature in the month of March is 1-2 oC below the normal value, there has been delay in wheat maturity by 7 to 10 days and an increase in wheat yield is

by 4-6 quintal per ha have been observed more compare `to other years.

As a conclusion it can be said that in this irrigated area, the effective beginning and end of rice growing season is determined by temperatures and rainfall distribution. For getting maximum yields it is necessary that the rice must be planted at the time i.e. in last week of June where optimum temperature conditions are met and since then the flowering will reach the date before night temperature falls below 20 0C. The results further showed that, over the years in wheat for each degree rise in air temperature and lack of winter rains, there has been reduction in yields by 5 to 10 % in timely and late sown wheat, while there has been reduction in yields by 10 to 20 % in early and late planted rice due to early withdrawn of monsoon and decrease in air temperature in the month of October. So in general, it can be concluded that there has been impacts of climatic variability in long term monitoring of the rice and wheat crops and their productivity also depends upon the use of standard agronomic practices and control measures. Early rise in air temperature in the month of March due to lack of winter rains adversely affects the wheat yields. This type of study will be of immense use for a location, if the long range weather forecast for important climatic variables such as rainfall and temperature are is available well in advance, the productivity of rice and wheat can be assessed for that location and it will promote in deciding the optimum sowing dates of wheat after rice as well as in scheduling the irrigation as well as for taking control measures for maximizing their production.

INTRODUCTION

In India, wheat is grown in 24.2 m ha area and out of this 50 to 70 % wheat is taken in rice-wheat rotation. Rice – wheat cropping system occupies first place in area (around 11 m ha), and production (more than 150 million tonnes) in India (India, 2002). Nearly 25 % of the total rice area of the country is grown in rotation with wheat (Sen and Sharma, 2002) and it is the backbone of country's food security with yield potential of 8.12 t ha^{-1} year^{-1} (Singh and Singh, 1996 and Bhandari *et al.*, 1992). The productivity of wheat in this rotation is very low due to many factors. Some of the problems in rice-wheat rotation for the cultivation of wheat crop are firstly due to the delayed wheat sowing (temperature gets reduced) as the harvesting of rice generally gets prolonged till the end of November and secondly due to the nature of puddled soil which develops large clods on ploughing which can not be managed by ordinary implements etc. Increasing nitrogen level mitigates the deleterious effect of puddling and flooding on wheat yield. Additional 60 kg N ha^{-1} applied to hasten the decomposition of rice stables at ploughing over normal management was found suitable. The rice-wheat cropping system is a very important and popular cropping system being following in the *tarai* area of Uttarakhand. The area, characterized by high water table and moist soil regime, lies with a narrow east-west strip of 8 to 25 km wide, on an outwash plain, gently slopping (<1 %) southwards below the Bhabar tract along the foot hills of the Himalayas. The entire area is dissected by a number of small streams originating as springs from the junctions of Bhabar and *tarai* belts. In India, about 4.8 m ha million hectare area cultivated under rice-wheat cropping system falls in *tarai* belt of Uttarakhand. The sowing of wheat after rice is being followed since about more than three decades after bringing the area under crop cultivation since its deforestation in 1950. In the study area, a complete recommended set of standard agronomic practices is followed including timely control of pests and diseases, proper integrated nutrient management, application of balanced fertilizers and crop residue management, recommended tillage practices after harvesting of rice and control of weed flora over a time period under different conditions and crop stages for in rice-wheat cropping system. In-spites of these, the yield of wheat after rice in the area has declined by about 20-30 % after the green revolution. It was thought that this decline in tend may follow the change in climatic conditions specially the air temperature and the rainfall in the area.

Therefore, in the present investigation this region has been selected for evaluating the productivity and sustainability of rice-wheat cropping system by analyzing the climatic conditions over past 45 years and correlates them with the yields of rice and wheat. Detailed analysis of monthly temperatures were carried out to determine the effective and critical temperature ranges for wheat and rice for this region for maximizing their yields.

MATERIAL AND METHODS

The present investigations were carried out at G. B. Pant University of Agriculture & Technology, Pantnagar (29^o N lat., 79^o 30 'E long. and altitude 243.84 m amsl), Uttarakhand. The area called *tarai*, lies in the foothills of Himalayas. The climate of the reason is humid sub-tropical with severe cold (lowest minimum temperature 2.0 $\pm$ 1.5) during winter and hot (highest maximum temperature 43.0 $\pm$1.0) during summer. The average annual rainfall of the region is 1433.4 mm of which 90 % rainfall is received during south - west monsoon season from mid June to end of September. The soils of *tarai* are mainly sandy loam to clay loam, coarse to fine texture having good moisture storage capacity, highly productive, associated with shallow to deep water table conditions and are classified as Mollisols. The physical and chemical properties of the soil are described by Deshpande *et al.* (1971). The rice yield data for 45 years from kharif season of 1961 to 2005 and wheat yield data from rabi season of 1961-62 to 2005-06 was collected from the Pantnagar University Farm, where standard agronomic practices were followed for raising these crops. The meteorological data was collected from meteorological observatory of the University located within the University Campus. The simple regression equation as well as curvilinear regression analysis (Ezekiel and Fox, 1959) was employed to develop regression equations between change in yields of Rice and Wheat with changes in climatic variables specially the seasonal rainfall, number of rainy days and maximum, minimum and average temperatures using statistical programs. Five year averages on these weather variables were also correlated with average yields to study the trend of variation in yields of Rice during kharif season (June to October) & for Wheat during Rabi season (November to April) over 45 years for Tarai & Bhabar agroclimate zone of Uttarakhand.

1. The simple regression equation was used with the help of statistical program which is as follow:

$$\mathbf{Y = m + a X}$$

Where Y = Yield of crop (kg / ha),

X = Weather parameter, for which regression equation is developed m & a are the constants.

2. The curvilinear regression analysis (Ezekiel and Fox, 1959) employed to develop regression equations was

$$\mathbf{Y = a + f_1 (X_1) + f_2 (X_2) + f_3 (X_3) + f_4 (X_4)}$$

Where, Y = Yield of crop, kg / ha for Rice or Wheat,

X_1 = Rainfall (mm),

X_2 = Maximum Temperature (°C)

X_3 = Minimum Temperature (°C), X_4 = Average Temperature (°C)

RESULTS AND DISCUSSION

Five years' average data of rainfall, number of rainy days, maximum and minimum temperatures weather variables for crop growing seasons for rice (June to October), and for wheat (November to April) and the rice and wheat yield for 45 years i.e. from 1961-62 to 2005-06 were analyzed. The five year average seasonal weather variables viz. rainfall (mm), average number of rainy days, maximum and minimum temperatures (°C), during rice and wheat growing seasons over past 45 years from 1961 to 2006 of study area are shown in Fig.1 and Fig.2, respectively. The average seasonal change in maximum temperature and minimum temperature was found to be are 0.4 and 0.2 ^{0}C, respectively during kharif season (Fig.1). However during rabi season from 1961- 65 to 2001 – 05, the average seasonal change in maximum temperature and minimum temperature were 0.4 and 0.4 ^{0}C, respectively (Fig.2). Two statistical techniques *viz.* linear and curvilinear regression techniques were employed in assessing the impacts of climate change on Rice & Wheat yields :

A. Impact of Climate change on rice yield

The following linear regression equations were developed between rice yields and rainfall, number of rainy days, maximum & minimum temperatures are given below :

a) Effect of rainfall distribution on rice yield

The linear regression equation obtained for rainfall distribution on rice yield was

$$\mathbf{Y = 4096.07 - 0.1380 X}$$

The coefficient of determination (R^2) obtained was 0.0026.

b) Effect of number of rainy days distribution on rice yield:

The linear regression equation obtained for number of rainy days rainfall distribution on rice yield was

$$\mathbf{Y = 3156.75 + 16.699 X}$$

The coefficient of determination (R^2) obtained was 0.0124.

c) Effect of maximum temperature distribution on rice yield:

The linear regression equation for maximum temperature thus obtained is given below:

$$\mathbf{Y = 16555.86 – 385.51 X}$$

The coefficient of determination (R^2) obtained was 0.0429.

d) Effect of minimum temperature distribution on rice yield:

The linear regression equation for minimum temperature thus obtained is given below:

Y = -24279.1 + 1231.13 X

The coefficient of determination (R^2) obtained was 0.2089.

The impact of five years average variations of rainfall on rice yield is shown in Fig. 3a and that of average number of rainy days in Fig. 3b. The trend clearly indicates that there has been effect of seasonal rainfall on rice yields but its distribution has significantly contributed towards the yields. In general years in which rainfall is sufficient to meet the water requirement of rice, more yields have been observed. However, heavy rainfall at the end of the season has adversely affected the rice yields except some variations. Number of rainy days has also contributed in the same manner (Fig. 3b).

B. Impact of Climate change on wheat yield

The following linear regression equations were developed between wheat yields and rainfall, number of rainy days, maximum & minimum temperatures are given below :

a) Effect of rainfall distribution on wheat yield

The linear regression equation obtained for rainfall for wheat was

Y = 2865.49 + 1.591 X

The coefficient of determination (R^2) obtained was 0.0103.

b) Effect of number of rainy days distribution on wheat yield:

The linear regression equation obtained for number of rainy days distribution on wheat yield was

Y = 3034.19 + 1.222 X

The coefficient of determination (R^2) obtained was 0.0314.

c) Effect of maximum temperature distribution on wheat yield

The linear regression equation obtained for maximum temperature for wheat was

Y = 13460.97 – 395.19 X

The coefficient of determination (R^2) obtained was 0.1547.

d) Effect of minimum temperature distribution on wheat yield

The linear regression equation obtained for minimum temperature for wheat was

Y = - 1551.41 + 456.44 X

The coefficient of determination (R^2) obtained was 0.1616.

The impact of five years average variations of rainfall on wheat yield is shown in Fig. 4a and that of average number of rainy days in Fig. 4b. The data indicates that there has been effect of rainfall during winter season resulting due to western disturbances on wheat yields. Some years in which rainfall is well distributed during the season at intervals coinciding with the growth stage of the crop, there is increase in wheat yields. Under low rainfall conditions response of irrigation has been observed to optimized wheat yields. Under heavy rain conditions decline in yield has been observed (170.1 mm rainfall, 2617 kg ha $^{-1}$ yield) as shown in Fig. 4a. A similar trend was observed on average number of rainy days affecting wheat yields (Fig. 4b).

C. Effect of climate change on change in rice yields

The study was made to assess the change in rainfall, maximum, minimum and average temperatures on change in rice yields for over 45 years from kharif 1961 to 2005 seasons. The following curvilinear regression equation for rice was developed

$$Y = 6.344 - 1.02 X_1 + 3.45 X_2 - 0.0157 X_3 - 4.073 X_4$$

$$R^2 = 0.712$$

This shows that in this area about 71 % (coefficient of regression, R^2 = 0.712) variations in rice yield and were due to variations in south-west monsoon rainfall and temperature conditions prevailed during kharif season.

The graphical representation between changes in rainfall and average number of rainy days on rice yield are given in Fig. 5, while the effect due to changes in maximum and minimum temperature is given in Fig. 6. It is evident from the analysis that there was maximum positive increase in rice yield (2037 kg ha^{-1}) during the year 1986 – 90 to 1991 – 95 (F) except during 1991 – 95 to 1996 – 2000 (G, 1090 kg ha^{-1}, Fig. 5), where there was a decrease in yield due to heavy rainfall. It may be due to flower dropping or lodging of the crop in the time of maturity. Fig. 6 clearly indicates that almost there was no significant change in minimum temperature (0.2 ^{0}C), during the kharif season; however the maximum temperature indicated influence on change in rice yields. Highest decrease in rice yield (1090 kg ha^{-1}) was observed during 1991 – 95 to 1996 – 2000 (G), as a result of decrease in maximum temperature (- 1.2 ^{0}C) during this period, followed by 1976 – 80 to 1981 – 85 (- 0.6 ^{0}C). This is slightly contrary to the findings reported by Sinha and Swaminathan (1991) in which a 2 ^{0}C increase in mean air temperature could decrease rice yield by about 0.75 tonnes per hectare in the high yield areas.

D. Effect of climate change on change in wheat yields

During rabi season (November and April), the impact of change in rainfall, maximum, minimum and average temperatures on change in wheat yields for over 45 years from rabi 1961- 62 to 2005 – 06 seasons was assessed. The following curvilinear regression equation for wheat was developed

$$Y = 12.767 - 1.080 X_1 + 0.261 X_2 + 1.917 X_3 + 1.632 X_4$$

$$R^2 = 0.924$$

This shows that in this area about 92.4 % (coefficient of regression, R^2 = 0.924) variations in wheat yields were due to variations in winter rains and favorable temperature conditions prevailing during the rabi season in the area.

The graphical representation between changes in rainfall and average number of rainy days on wheat yield are given in Fig. 7, while the effect due to changes in maximum and minimum temperatures is given in Fig. 8. It is evident from the analysis that there was maximum positive increase in wheat yield (1182.2 kg ha^{-1}) during the years 1986 – 91 to 1991 – 96 (F1) except during 1971 – 76 to 1976 – 1981. A significant decrease in yield observed during 1971 – 76 to 1976 – 1981 (C1, 509 kg ha^{-1}) and 1996 – 01 to 2001 – 2006 (H1, 535 kg ha^{-1}, Fig. 7) due to high rainfall during flowering to maturity stage. Fig. 8 clearly indicates that almost there was no significant change in minimum temperature (0.4 ^{0}C), during the rabi season, however, the changes in maximum temperature influenced wheat yields. Highest decrease in wheat yield (535 kg ha^{-1}) was observed during 1996 – 01 to 2001 – 2006 (H1), as a result of increase in maximum temperature (0.4 ^{0}C) during this period, followed by 1981 – 86 to 1986 – 91 (0.6 ^{0}C, 280.8 kg ha^{-1}). This agrees with the findings reported by Sinha and Swaminathan (1991), where a 0.5 ^{0}C increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 tonnes per hectare. Wheat yield was also found to decreased with decrease in temperature during 1971 – 76 to 1976 – 1981 (C1,- 0.4 ^{0}C, 509 kg ha^{-1}). However, an increase in winter temperature of 0.5 ^{0}C would thereby translate into a 10 % reduction in wheat production in the high yield states of Punjab (Sinha and Swaminathan, 1991).

CONCLUSION

1. The effective beginning and end of rice growing season is determined by temperatures and rainfall distribution and for getting maximum yields, it is necessary that the rice must be planted at the time i.e. in last week of June where optimum temperature conditions are met.

2. There was maximum positive increase in rice yield (2037 kg ha^{-1}) during the year 1986 – 90 to 1991 – 95 (F) except during 1991 – 95 to 1996 – 2000 (G, 1090 kg ha^{-1}, Fig. 5), where there was a decrease in yield due to heavy rainfall. It may be due to flower dropping or lodging of the crop in the time of maturity.

3. Highest decrease in rice yield (1090 kg ha^{-1}) was observed during 1991 – 95 to 1996 – 2000 (G), as a result of decrease in maximum temperature (- 1.2 ^{0}C) during this period, followed by 1976 – 80 to 1981 – 85 (- 0.6 ^{0}C).

4. The results further showed that, over the years in wheat for each degree rise in air temperature and lack of winter rains, there has been reduction in yields by 5 to 10 % in timely and late sown wheat, while there has been reduction in yields by 10 to 20 % in early and late planted rice due to early withdrawn of monsoon and decrease in air temperature in the month of October.

5. A significant decrease in wheat yield observed during 1971-76 to 1976 – 1981 (C1, 509 kg ha^{-1}) and 1996 – 01 to 2001 – 2006 (H1, 535 kg ha^{-1}, Fig. 7) due to high rainfall during flowering and maturity stage of wheat crop.

6. Highest decrease in wheat yield (535 kg ha^{-1}) was observed during 1996 – 01 to 2001 – 2006 (H1), as a result of increase in maximum temperature (0.4 ^{0}C) during this period, followed by 1981 – 86 to 1986 – 91 (0.6 ^{0}C, 280.8kg ha^{-1}). However wheat yield was also found to decrease by decrease in temperature during 1971 – 76 to 1976 – 1981 (C1, - 0.4 ^{0}C, 509 kg ha^{-1}).

So in general, it can be concluded that there has been impacts of climatic variability in yields of rice and wheat crops and their productivity also depends upon the use of high yielding varieties, follow of standard agronomic practices and control measures. This type of study will be of immense use for a location, if the long range weather forecast for important climatic variables such as rainfall and temperature are available well in advance, the productivity of rice and wheat can be assessed and forecast for that location and it will promote in deciding the optimum sowing dates of wheat and rice as well as in scheduling the irrigation and for taking control measures for maximizing their production.

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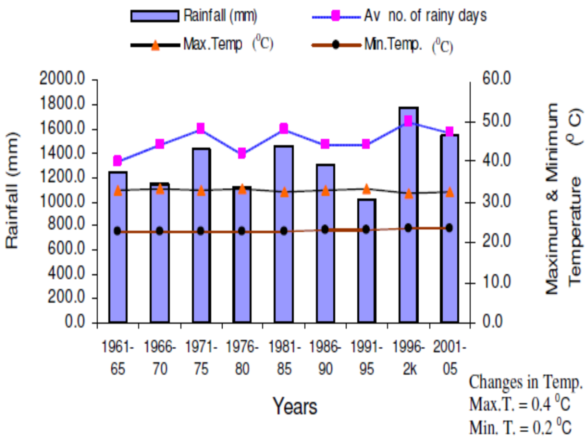

Fig 1 : Five years' average seasonal variations in rainfall (mm), average number of rainy days, maximum and minimum temperatures (^{0}C) for 45 years during Kharif season (June, 1961 to October, 2005) at Pantnagar.

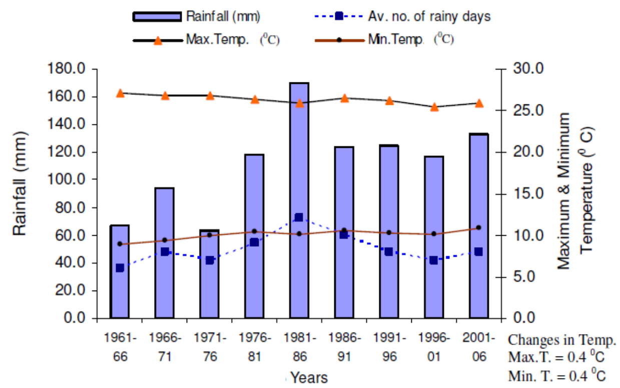

Fig 2 : Five years' average seasonal variations in rainfall (mm), average number of rainy days, maximum and minimum temperatures (^{0}C) for 45 years during Rabi season (November, 1961 - 62 to April, 2005 - 06) at Pantnagar.

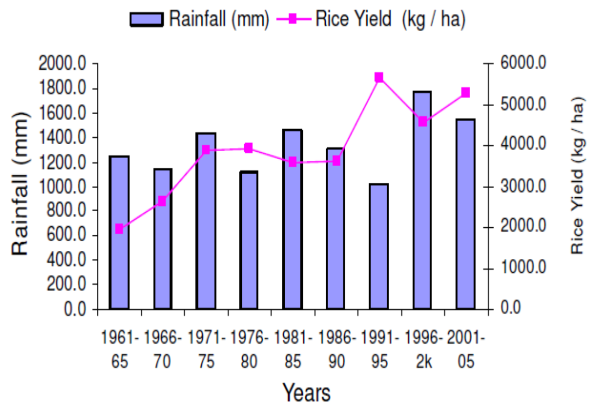

Fig 3 (a) : Five years' average variations in rice yield (kg / ha) and rainfall (mm) for 45 years from 1961 to 2005 at Pantnagar.

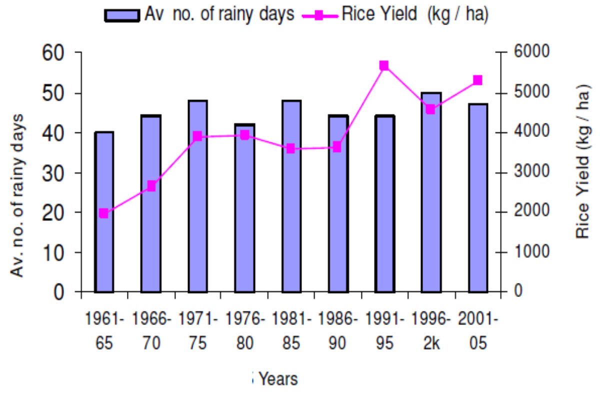

Fig 3 (b): Five years' average variations in rice yield (kg / ha) and average number of rainy days for 45 years from 1961 to 2005 at Pantnagar.

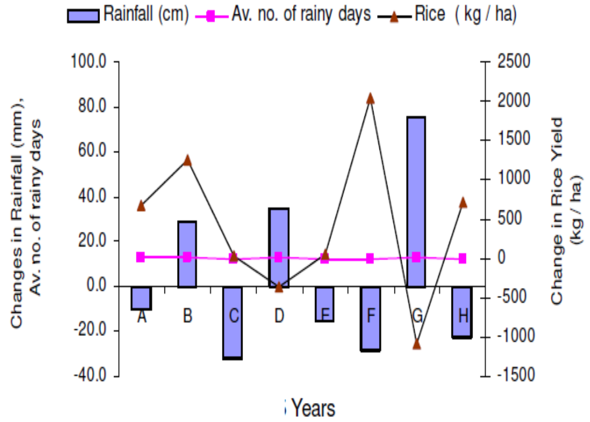

Fig 5 : Change in rice yield vs changes in rainfall (mm) and average number of rainy days for 45 years from 1961 to 2005 at Pantnagar.

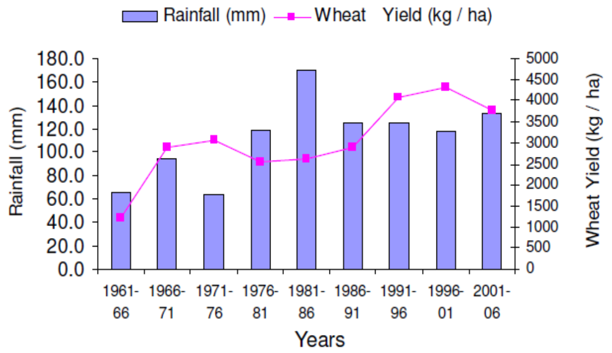

Fig 4 (a): Five years' average variations in wheat yield (kg / ha) and rainfall (mm) for 45 years from 1961- 62 to 2005 - 06 at Pantnagar.

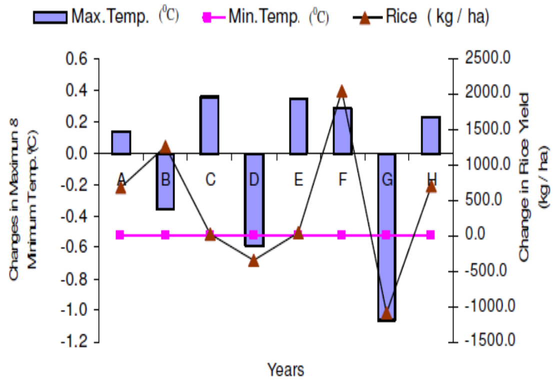

Fig 6 : Change in rice yield vs changes in maximum & minimum temperatures (^{0}C) for 45 years from 1961 to 2005 at Pantnagar.

A	1961 - 65 to 1966 - 70	B	1966-70 to 1971-75
C	1971 - 75 to 1976 - 80	D	1976-80 to 1981-85
E	1981 - 85 to 1986 - 90	F	1986 - 90 to 1991-95
G	1991 - 95 to 1996-2000	H	1996 - 2000 to 2001 - 2005

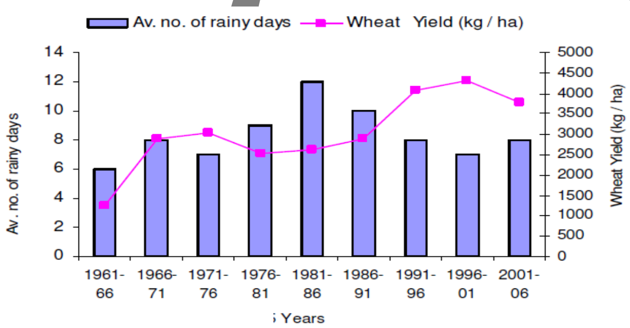

Fig 4 (b): Five years' average variations in wheat yield (kg / ha) and averag number of rainy days for 45 years from 1961- 62 to 2005 - 06 a Pantnagar.

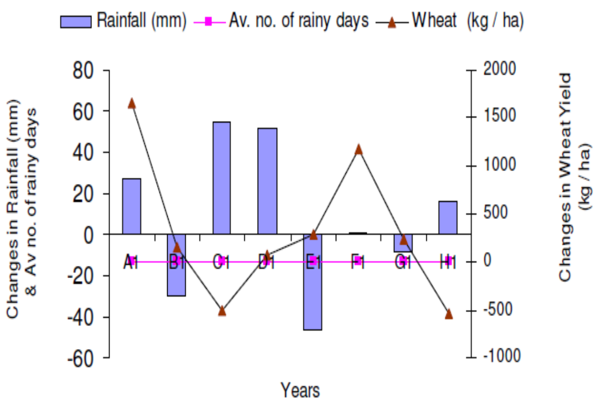

Fig 7 : Change in wheat yield vs changes in rainfall (mm) and average number of rainy days for 45 years from 1961- 62 to 2005 -06 at Pantnagar.

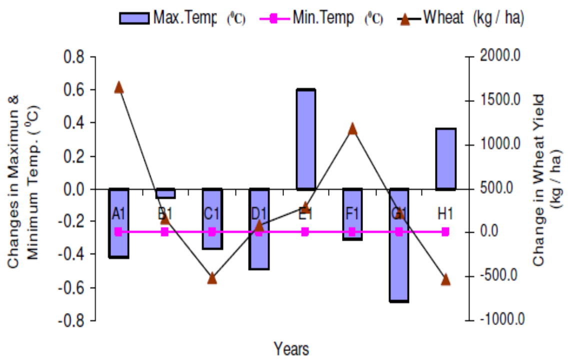

Fig 8 : Change in wheat yield vs change in maximum & minimum temperatures (^{0}C) for 45 years from 1961- 62 to 2005- 06 at Pantnagar.

A1	1961 - 66 to 1966 - 71	B1	1966-71 to 1971-76
C1	1971 - 76 to 1976 - 81	D1	1976-81 to 1981-86
E1	1981 - 86 to 1986 - 91	F1	1986 - 91 to 1991-96
G1	1991 - 96 to 1996-2001	H1	1996 - 2001 to 2001 - 2006