Rainfall Variability and Maize Production over the Potohar Plateau of Pakistan

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Abstract

Pakistan is an agricultural country, having diverse climate and almost two third area experiences arid type climate. Maize (Zea Mays L.) is the second most important cereal crop after wheat in Pakistan but its yield per unit area is very low. Climatic Variability has direct and adverse impact on the food production and sustainable development especially in rainfed areas. Along the foot-hills of Himalayas, a vast agriculture plain known as Potohar Plateau is isolated. Among climatic factors, the precipitation has great influence on the production of crops. Potohar Plateau is known for its highly variable precipitation characteristics both in terms of frequency and distribution. In this study, it has been found that during vegetative and reproductive stages, as the rainfall increases from 100 mm to 250 mm and 50 mm to 200 mm respectively, the yield has been improved resulting in to maximum production i.e. 2400 Kg/Ha at certain amount of precipitation. Maize is generally planted in July with the onset of the monsoon (rainy season) and it attains maturity as the monsoon recedes from Pakistan in September. After crossing the peak values 300 mm during the growing season, the yield decreases with the increase in rainfall. Planting season is highly risky. If there is persistent rain, it does not provide gap to the soil suitable for seed sowing. On the other hand, if monsoon is delayed then deficient soil moisture fails to sustain the seed germination process. Moreover, maize plant is highly sensitive to moisture surplus and deficit. At an early stage, heavy rain may destroy the whole cultivar due to heating up of stagnant water in the maize field which blocks the pores of the soil. If not total destruction, the plant population reduces to that low resulting in uneconomic yields. The relationship between rainfall and the yield proved true and highly significant correlation has been found at all the four stations i.e. Chakwal, Rawalpindi, Kamra and Jhelum. Well correlated yield with the rainfall amount at early stage of crop development helps to develop a model for yield prediction with a sufficient lead time which may be used by planners and policy makers to manage the probable shortages or surpluses. Curvilinear models have been developed depicting the precipitation amount and maize production for different agricultural zones of Potohar Plateau.

Introduction

The climate of Pakistan is uneven and almost two third of the country demonstrate arid type climate. A narrow belt of sub mountainous regions illustrate humid climate. Most of the regions in central and southern Pakistan are tremendously arid, while the northern part of the country is humid except the extreme northern mountains which are relatively dry. The mountainous region composed with lofty hills in the northern and northeastern sides experience the type of climate having similarities with temperate climate and some areas in the south experience an arid and semi arid climate with low precipitation and high temperature (Chaudhry and Rasul, 2004).

The Agriculture in Pakistan depends upon water from rainfall and also melting of ice and snow and glacier ice. Monsoon is the foremost source which recharges moisture to the soil in Potohar region. The area lies between 33.00º N to 36.00º N experience semi arid to humid climate where crop may be growing successfully. Temperature is increasing beyond its normal limits due to natural processes and also because of non environment friendly human activities. High temperature may have optimistic impact on the production of crop. From sowing to wax maturity stages water is the basic requirement of the plant after wax maturity stage there is no need of water to the plant for its growth. Climate change is influencing the socio-economic conditions particularly the population relying on agriculture. Pakistan also faces the problems like Glacier melting, flash flood, drought, rising heat index and insufficient water for crops. Crop water requirement mainly depends upon climatic factor such as Air temperature, solar radiation, relative humidity, wind speed and agronomic factors like stages of the crop (Ghazala and Mahmood, 2009).

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The Potohar Zone lies from about 32.5˚N to 34.0˚N Latitude and from about 72˚E to 74˚E Longitude. The crops grown in Potohar include wheat, maize, barley, bajra, gram and groundnut. Out of total about 80% rain, falls during July to October and mainly supports the efficiency of the maize. There have been a number of studies on crop productivity in rainfed areas yet there is lack of systematic study, under the condition of deficiency of water supply, how the productivity of maize crop could increase at different levels. Potohar region lies between Indus River and the Jhelum River and stretches from the salt range northward to the foot hills of Himalayas. The Potohar region thus embraces the major portion of Attock, Jhelum, Rawalpindi and Chakwal. Total area of Potohar region is 28488.9 sq Km. The best suited area is mainly located between 33.0º N and 35.0ºN latitude where the food crop production is possible under rainfed conditions (Chaudhry et al., 2004).

Life cycle of maize crop depends much upon water availability, the water deficit at any phonological stage i.e. vegetative, reproductive and maturity stages have different response and can damage the grain yield (Chkir, 2004). Drought is harmful for crop growth and development. In simple words, drought is the lack of water availability. Drought stress also damages the grain yield when it occurs at reproductive stage of crop's life cycle (Heisey and Edmeades, 1999). During stem elongation, the development and growth of leaves and stem is so rapid that it requires sufficient amount of water, the water stress at that stage can reduce the height of plant and also affects the leaf of plant (Muchow, 1989). The most crucial time of water stress in maize crop is ten to fifteen days before and after flowering. At this stage if the water deficit occurs then the grain yield decrease two to three times more than the water deficit in another growing stage. (Grant et al. 1989). Soils of the area are generally medium textured to clay-loam and are low in natural fertility, Nitrogen, organic matter and Phosphorus are deficient; however, potash level is adequate. The soils are having pH of 7.5 to 8.5 (Ahmad et al., 1988).

Methodology

Six meteorological observatories are functioning in Potohar region. They collect the data of different meteorological parameters such as maximum temperature, minimum temperature, dry bulb temperature, wet bulb temperature, wind velocity and direction, Atmospheric pressure, rainfall, sunshine duration, relative humidity etc.

In this study, observed rainfall data of four meteorological stations i.e. Rawalpindi, Chakwal, Jhelum and Kamra are used, for the period 1991-2008, from data archives of PMD. Actual yield data for the said period is utilized as received from Crop Reporting Department of Punjab and Arid Agriculture University Rawalpindi.

The daily observed data of rainfall for particular locations is scrutinized and compiled on seasonal as well as annual basis. The data sets are separately analyzed to investigate the general trend by statistical software 'Excel'. "Scattered Plot" method has been employed to compare final yield produced versus rainfall during the growing season and for some critical water supply sensitive phonological stages during the life cycle of the maize crop. The Polynomial regression technique was employed to study the relationship of rainfall received at different stages and coefficients of correlation R^2.

Results and Discussion

The cropped area of Pakistan consists of 20.9 mha, of which 4.8 mha (24.4%) is rainfed, which includes Potohar uplands, northern mountains and northeastern plains (Anon., 1988). Maize serves as feed, food as well as fodder and is the high yielding cereal crop in the world. In Pakistan maize is the third chief cereal after wheat and rice, sown mainly in two seasons i.e. spring and the autumn. Spring maize is planted from the first week of February to first week of March while the sowing time for autumn maize starts from the last week of July and ends in mid of August.

In rainfed areas, rainfall plays an important role in the crop cycle. The yield totally depends upon the amount and intensity of rainfall. The study includes the effect of variability of rainfall on yield in Potohar

region especially the locations includes Rawalpindi, Karma, Chakwal and Jhelum because the crops in these areas totally depend upon spatial and temporal distribution of rainfall.

Precipitation Climatology of Study Area

Chakwal

Chakwal is located in the southern zone of Potohar plateau, lies at the latitude 33°N and longitude is 73°E. There is a great fluctuation in rainfall. During the study period mostly the amount of rainfall is less than the normal rainfall. This rainfall affects the yield of crop, poor yield is obtained in such a circumstances. The graph represents the variation of rainfall during the study period in Chakwal. It presents the total amount of rainfall of the year that has been recorded at meteorological observatory. Horizontal axis represents the year and the vertical axis represents the total amount of rainfall (mm) in the particular year .Solid line parallel to horizontal line shows the average of eighteen years and dotted line represents standard deviation ± 175.

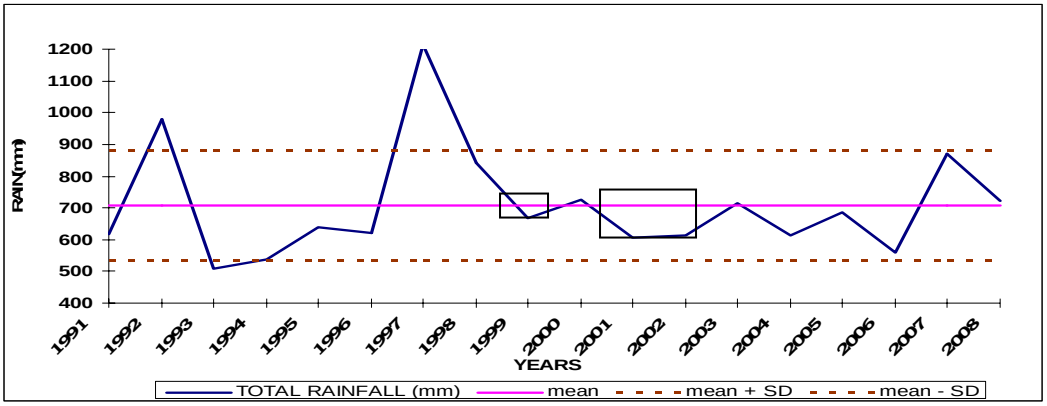

Figure 1: Inter-annual variation of Rainfall at Chakwal (1991-2008) with SD ±175. shaded region shows the longest drought spell of Pakistan.

A positive anomaly has been observed in the year 1992 and for the period 1997 and 1998 whereas negative anomalies observed during the year 1993. Average rainfall during the study period is 708 mm. The highest amount of rainfalls in 1997 and is recorded above 1200 mm. High variable pattern of rainfall at Chakwal reflect the uncertainties to which agriculture production is exposed.

Under consideration the second wettest year of the period was the year 1992 and the recorded rainfall is 979 mm. It is worth mentioning that 1992 was the year of the most horrible flooding in the river Jhelum. The driest year of the series was 1993 with 510 mm precipitation during the period. Standard Deviation plotted on both sides of the mean rainfall determines the optimum limits of inconsistency. Time series of eighteen years rainfall recorded at Chakwal reflects highly variable pattern of precipitation which could pose the agriculture practices in the region to a high level of uncertainty in terms of sustainable crop production.

Jhelum

Jhelum is district headquarters in Potohar zone where meteorological observatory has been operating since five decades but data used in this study covers eighteen years. It represents southeastern agriculture plains of plateau. The irony is that the Jhelum River passes through this area but due to its uneven elevation, river water could not be used for cultivation of crops. Agriculture is therefore totally dependent on the rainfall. Annual rain for Jhelum region has shown immense variability for the period 1992 -2008. During years 1996, 1997, 1998 and 2006 positive anomalies has been observed while negative anomalies existed in the years 1999 and 2002.

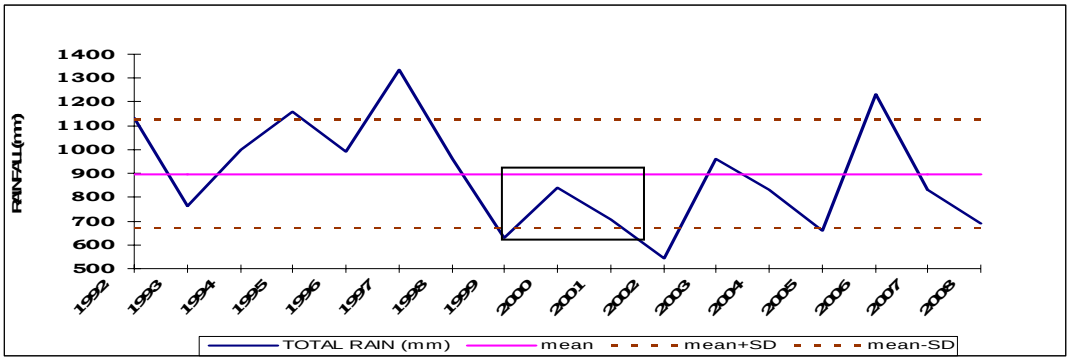

Figure 2: Inter-annual variation of rainfall at Jhelum (1992-2008) with SD ±225. Longest drought of Pakistan is depicted by shaded area.

Both negative and positive anomalies can affect the yield of crop due to surplus and deficit water respectively. The crop required specific amount of water, at regular time interval but the anomalous behavior of rainfall poses threat to crop production targets. Also soil texture and structure play a vital role in the development of plant because of water holding capacity.

The average rain falls in Jhelum amounting 900 mm. The highest amount of rain fall was recorded in 1997 which is slightly more than 1300 mm. The year 2007 is the second wettest year in time series. The driest year in the study period is 2002 followed by the year 1999. Dotted line represents standard deviation on both sides of the average rainfall which show optimum limits of variation of rainfall in Jhelum.

Time series analysis of Jhelum shows great variation in rainfall pattern which is beneficial as well as dangerous for crop production. This time series analysis helps in decision making for selection of a particular crop and also gives the optimal limits of rainfall in the particular region.

Kamra

Kamra is located in district Attock. The northern part is more humid with a relatively colder climate as compared to the southern part. It is located 348m above mean sea level on the average with variable altitudes of hills. Meteorological observatory at Kamra has been functioning for the last 25 years. The weather is highly variable with frequent heavy spells of rainfall and prolonged dry spells. Such variability increases the crop failure risks and untimely rains, sometimes, either prohibit the farmers to sow their crops or destroy the young crops with more than the required doses of water.

Annual rain for Kamra region has shown great fluctuation for the period 1992-2008. Positive anomaly occurred in the year 1994 whereas negative anomalies were during the year 2000 and 2001. The standard Deviation of rainfall in Kamra is 314 which are the highest among all the meteorological stations over the Potohar plateau. The range of rainfall during the study year is about from 620 mm to 1485 mm.

Average amount of rainfall during the study period is about 1060 mm. During the study almost in nine years the rain fall is less than the normal while 1994 and 2008 are the two wettest years. Also 2000 and 2001 represents the drought years in eighteen year study. Four years from 1999 to 2002 are the driest year.

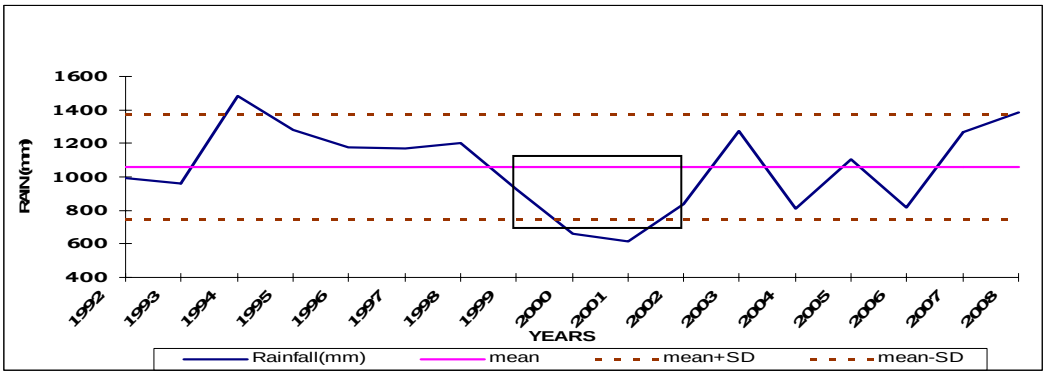

Figure 3: Inter annual variation of rainfall at Kamra (1992-2008) with SD ±314. The driest prolonged stretch in Potohar zone is shown by shaded area.

Rawalpindi

Rawalpindi is the fourth largest city of Pakistan and represents rainfed region of Potohar plateau. The cropping pattern in Rawalpindi purely depends upon rain fall. Rawalpindi is positioned at 517 meters above sea level. The climate of Rawalpindi is tropical with moderate temperatures throughout the year. Annual rain for Rawalpindi region has shown great fluctuation. Drought prevailed from 1999 to 2002. Almost in nine years amount of rainfall is greater than the average rainfall while in the remaining years during the study period is less than the average amount of rainfall. Year 1994 is the wettest and 2000 is the driest year. It is worth mentioning here that total amount of rainfall in the year 2001 enters in the list of normal rainfall year. In fact, this year was one of the driest year but a single day rainfall 62 mm on 23 July ranked it an average year. In rainfed areas the output totally depends upon the amount and frequency of rainfall which is unpredictable. Enormous variation above and below the average rainfall have been observed for long term as well as short term rainfall pattern. This variability directly influence in the field of agriculture, especially on maize crop. Drought is also the side effect of climate variability. The maize has not the potential to bear the surplus as well as the deficit of water.

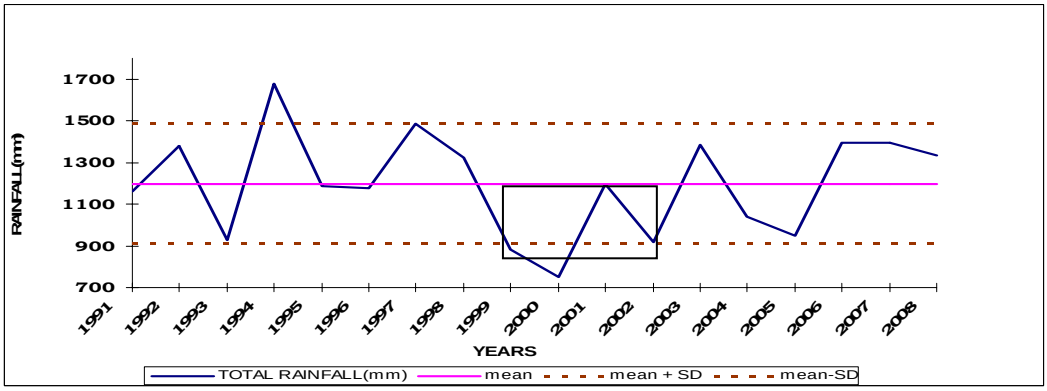

Figure 4: Inter annual variation of rainfall in Rawalpindi (1991-2008) with SD ± 286 shaded areas indicates the longest drought of Pakistan.

The vegetative and reproductive stages of maize crop dependent on rainfall. Economically, the maize crop is the best because it remains in the field for very short period i.e. for three to four months. In that short period the economic returns may increase by producing best quality of corn yield. Timely rain plays an important role in the development of crop. But unfortunately, in Rawalpindi the variation in the amount of rainfall badly affects the yield of crop. According to

the water requirement of maize crop the rain was not consistent, so the corn yield obtained in Rawalpindi is low, as compared to other locations of Potohar zone.

Effect of rainfall on Corn yield at different phonological stages

It is estimated that 65 percent of global food production depends upon rainfall, while the remaining 35 percent rely upon irrigation. Food production is highly affected by the annual and seasonal variation of rainfall. It is estimated that 60 to 80 percent of water is used in agriculture (Smith, 2000). Variability of rainfall is the universal risk for agriculture production. Irrigation is the obvious option for development and to increase the grain yield. Diversion of surface water and extracting of ground water are the major source of irrigation. There are two critical phases' i.e. vegetative and reproductive phases of maize crop, depends upon the concentration and frequency of rainfall. The excess and shortage of water during vegetative and reproductive stages may have negative impact on the final yield.

Effect of rainfall on Corn yield at Chakwal

Rainfall pattern and its characteristics play an important role in field operations. Inadequate water supply possesses negative impact on agriculture production. It is the fact that success and failure of crop production in rainfed areas is precipitation, the dependence has been investigated. Maize crop in Potohar is generally planted after the onset of monsoon season in July, when plenty of water is available in the soil to support growth and development of plants. The growing season of maize crop in Potohar spans over four months i.e. from July to October. The scattered diagram represents the relationship of grain yield of maize crop with total rainfall during different phonological stages in Chakwal. The Scattered diagram represents the total growing season, vegetative and reproductive stages of maize crop. Growing season spans about 87- 90 days in Potohar region after planting.

Under the optimum soil moisture conditions, the plant continues growing. During the growing season in Chakwal the amount of yield is increasing as the amount of rain occurred between 200 to 360 mm. On the other hand rain has shown inverse impact on yield when it occurred more than 360 mm. Figure 5a represents the yield increase with increase in rainfall during the vegetative phase and it reaches the maxima at 360 mm. More rain causes the sharp decline in final yield apparently due to stagnant water in the fields which heats up and destroys the roots of plants. Poor yield is obtained due to high amounts of precipitation at an early stage of crop growth. The reproductive stage is the most significant phase in the life cycle of maize plant. It consists of the cob formation, silking, Tassling, pollination and grain formation. All these processes take place very consistently and complete in a span of 15 – 20 days. Reproduction is a very sensitive phases in which a little shortage of water causes a drastic fall in economic yield. The correlation between rainfall and the grain yield during growing, vegetative and reproductive stages are 59%, 61%, 60% respectively.

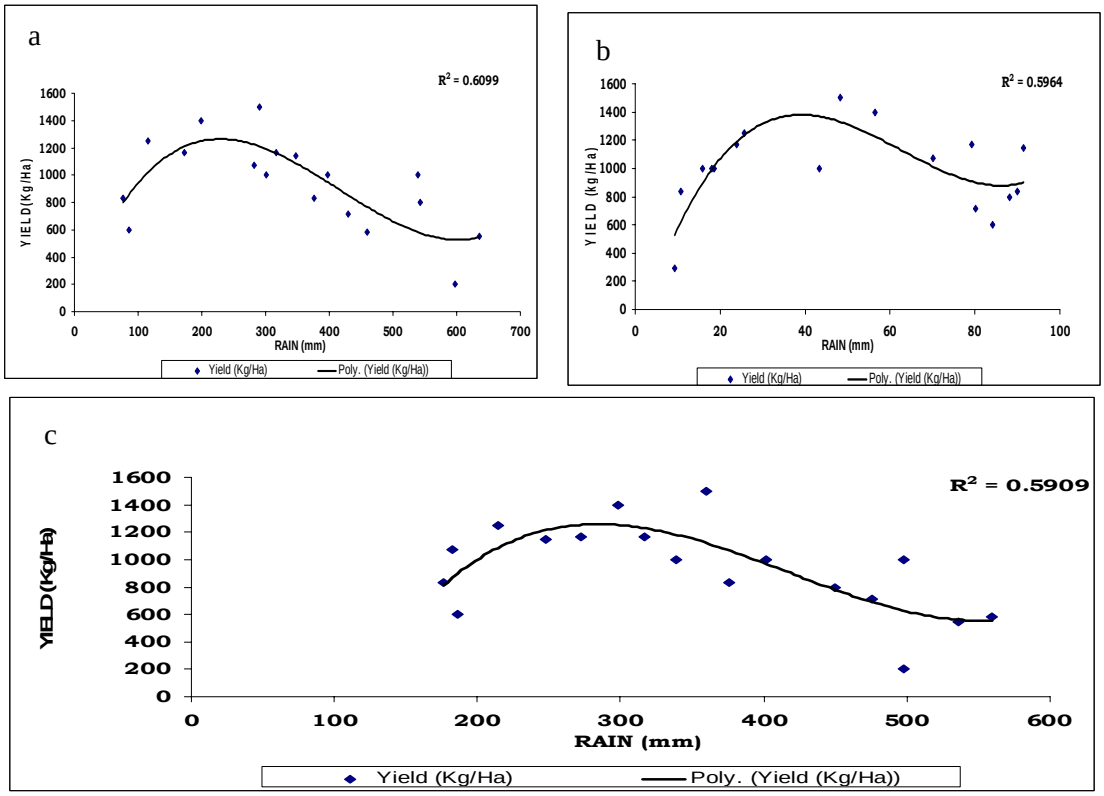

Figure 5: Relation of rain (mm) with grain yield (Kg/Ha) at Chakwal (1991-2008)
(a) Emergence to 9th Leaf vegetative interphase.
(b) Tassling to Flowering reproductive Interphase
(c) Growing season from July to October.

Effect of Rainfall on Corn Yield at Jhelum

Maize is a Kharif crop that grows in warm places. After one week from sowing the crop required sufficient amount of water. The monsoon rainfall fulfills the water requirement of maize crop grown in Potohar. The above diagrams show the relation of rainfall and the Corn yield at different phonological stages. Figure 6c represents the relationship of yield with total rainfall during the growing season of maize crop which spans over four months. Figure 6a and 6b shows effect of rainfall on the corn yield which occurs during represents the vegetative and reproductive stages in Jhelum. The scattered diagram shows that up to approximately 450 mm rain, the grain yield increases, when the crop gets precipitation more then 450 mm then the grain yield decreases, because runoff water effects on the fertility of soil. Due to loss of fertility of soil it is not possible for plant for its proper development and growth in such an odd situation. The amount of yield obtained in such situation is very bad and it directly effect on the economy of Pakistan.

Also the total amount of rainfall of approximately 200 mm during vegetative stage and 250 mm is required during reproductive stage to get maximum yield. The correlation between total rainfall of the season and the grain yield is 55%, at vegetative phase 66%, and during reproductive phase is 58%.

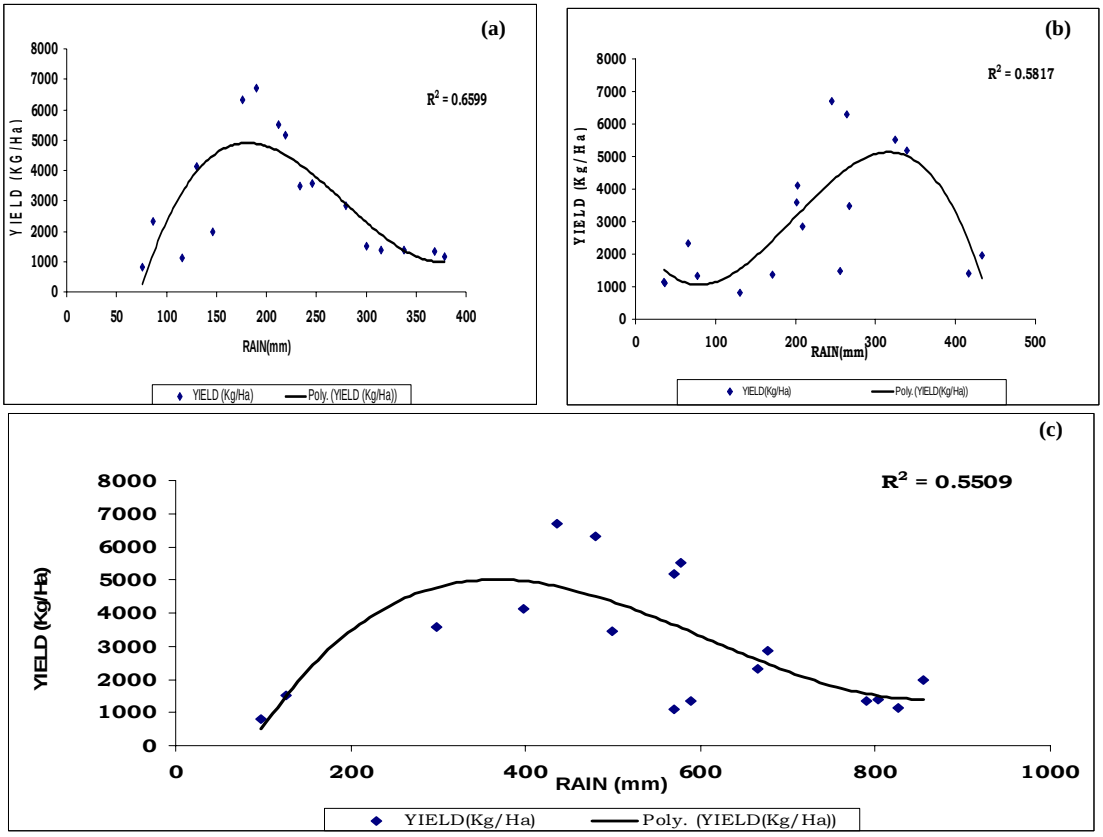

Figure 6: Relation of rain (mm) with grain yield (Kg/Ha) of maize at Jhelum (1992-2008)
(a) Emergence to 9th Leaf (vegetative phase)
(b) Tassling to Flowering (Reproductive phase)
(c) Growing season from July to October.

Effect of Rainfall on Corn Yield in Kamra

Maize is a major ingredient in infant brewery and poultry feed industries. The limiting factor for crop production in Potohar region is water. Adequate rainfall is very important during germination and the first month of the growth. Above diagrams show the relationship between the rainfall and Corn yield obtained in Kamra. The highest amount of grain yield obtained when there is rainfall of 440 mm during whole growing season. Figure 7c shows that from 200 mm to 440 mm the amount of grain yield increases as the crop gets rain more than 440 mm the grain yield decreases. During vegetative and reproductive phases 280 mm and 200 mm respectively rainfall is required for best production. The correlation between rain and the grain yield is 63%, 69 %and 61% during whole season, vegetative and reproductive stages respectively.

The excess as well as shortage of rain fall both are dangerous for crop and leave direct impact on the final yield. The excess of rainfall is dangerous for fertility of land also the shortage of water cause drought.

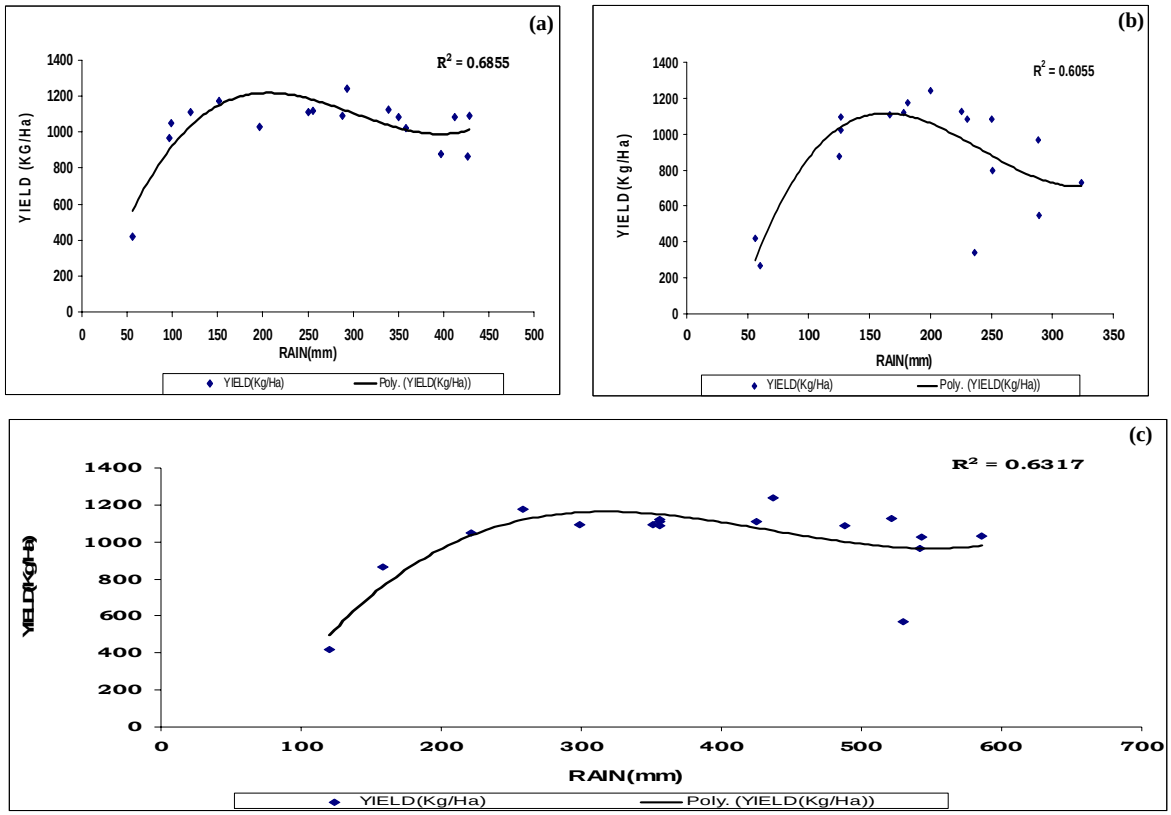

Figure 7: Effect of total rain on corn yield at Kamra 1991-2008 at different phases
(a) Emergence to 9th Leaf (Vegetative Interphase)
(b) Tassling to Flowering (Reproductive Interphase)
(c) Growing season from July to October.

Effect of Rainfall on Corn Yield at Rawalpindi

During the life cycle of plant, it passes through different phonological stages. Every stage has its own importance and also require significant amount of water for the development and growth. By improving the physical and chemical condition of soil, it reduces water runoff, increases rain water infiltration, enhancing nutrients availability, improving root proliferation and weed control. The scattered diagrams represent that the significant amount of rain is required at different development stages for acquiring sufficient amount of grain yield. The highest amount of final yield is obtained when there was a total rain of 680 mm. At vegetative phase the total amount of about 270 mm rain is required to get maximum final yield.

Whereas at reproductive phase the highest amount of yield is obtained when 200 mm rain occurred in Rawalpindi. The correlation between the grain yield and the total amount of rainfall during growing season was 54%. Growth and development of a plant are a wonderful combination of many events at different stages. The event which plays the most important role in the development of plant in rainfed zone is rainfall. Deficiency of water during the life cycle of maize crop is dangerous for crop also the maize crop did not bear the plentiful quantity of water, so it is necessary to drain off the extra water which is present in the field.

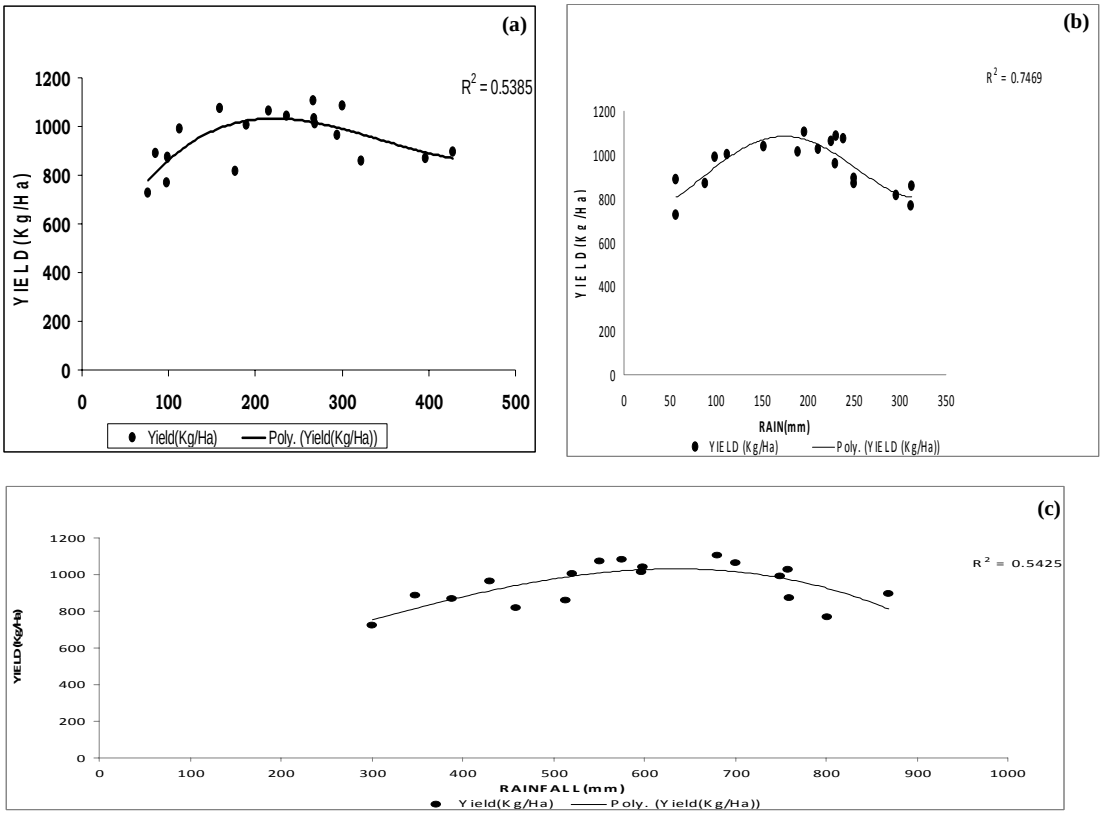

Figure 8: Relationship of rain (mm) with grain yield in Rawalpindi (1991-2008).
(a) Emergence to 9th Leaf **(b)** Tassling to flowering **(c)** Growing season

Effect of Rainfall on Corn Yield in Potohar Zone

Weather and climate play important role in selection of crop which could survive to give seasonal economic yield at certain location and at particular time. Maize is grown in Potohar climate both as food and fodder crop because this region receives sufficient monsoon precipitation to meet the water requirement. However, it has been seen that rainfall is beneficial if it lies in optimum limits beyond that it is detrimental. Insufficient rain cause drought while intense rain in short period reduces ground water recharge by accelerating runoff and causes flood. Both the situation influence negative impact on crop. Soil moisture availability gives the sowing date of maize crop in pre monsoon and later the sustained growth and development.

The scattered diagram shows the relationship of rainfall and the grain yield obtained in Potohar zone. Season for maize crop in Potohar zone consists of 87 to 93 days. The range of rainfall during the growing season in Potohar zone is from about 135 mm to 530 mm. The highest amount of final yield is obtained when there is a rain of about 300 mm during the growing season, at vegetative phase when there is a rain of 277 mm, at reproductive phase 168 mm. The correlation between the amount of rainfall and the final yield of maize obtained during growing season is 57.5%. Maize is very sensitive crop. Suitable amount of water is required for proper growth and development of maize crop, very minute deficiency of water at this stage damages the plant.

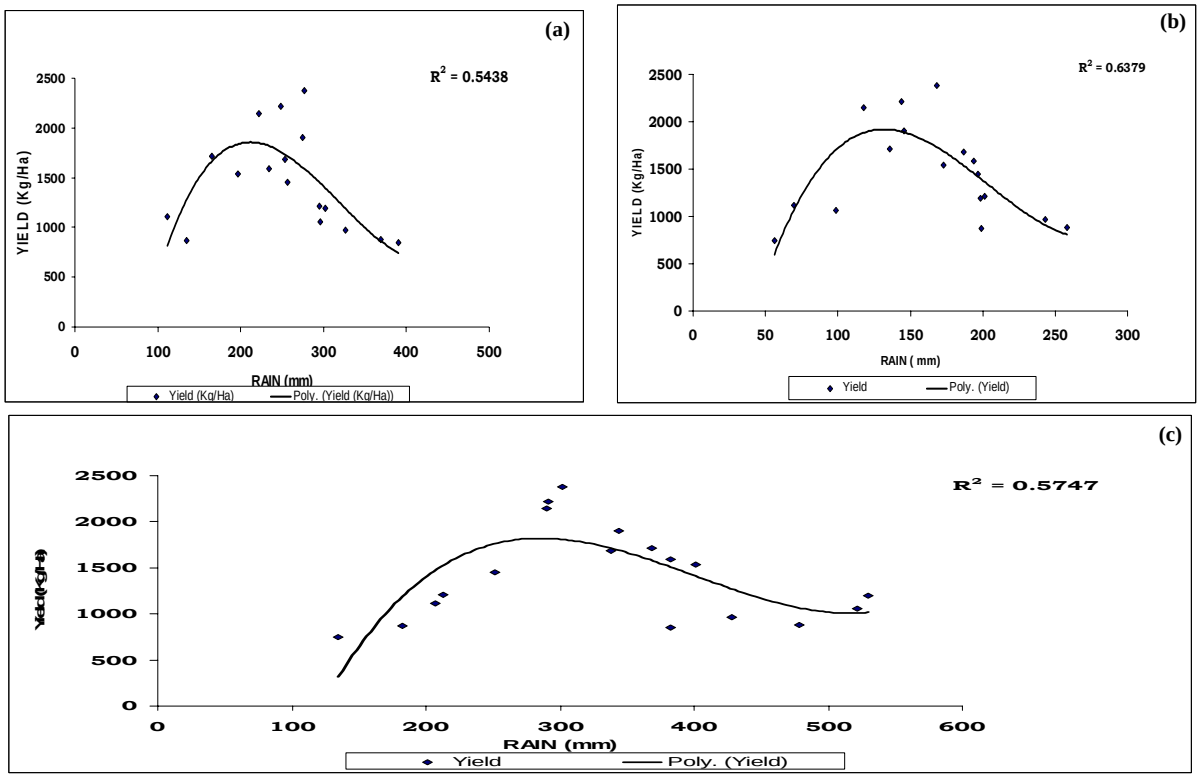

Figure 9: Relationship of rain (mm) with grain yield in Potohar zone
(a) Emergence to 9th Leaf **(b)** Tasseling to flowering **(c)** Growing season

Conclusion

Maize requires specific amount of water. In rainfed areas like Potohar Plateau the maize crop totally depends upon the amount and frequency of rainfall as well as its distribution on temporal and spatial scales. Excess or deficit rain badly affects the grain yield especially at early and reproductive stage of corn maize. The analysis revealed that increase in rain enhances the yield up to certain limits afterward the grain yield decreases. It is worth mentioning that the highest amount of rain fall in Rawalpindi was 680 mm during the growing season of maize crop but the yield obtained was less than the other locations. Following conclusions were drawn from the study:

- In general, the corn yield increases with increase in seasonal total rainfall from 250 mm to 400 mm over the agriculture fields of Potohar Plateau with relatively less slope. However, the larger amount of rainfall up to 700 mm at sharp slopes remains beneficial. Higher amounts of rainfall than these thresholds during whole growing season cause reduction in yield.
- Vegetation stage (3rd leaf to 9th leaf) is very critical. Yield increases if rain during this period ranges from 200-300 mm at uniform intervals. More rain results into grain yield drop.
- The most water sensitive stage of maize cop happened to be the reproductive one (Tassling / Silking to grain formation). Amount of rainfall ranging between 200 mm and 250 mm has yield enhancing effect whereas higher amount reduce.

On the average in Potohar Zone 300 mm rainfall is required during growing season, 250 mm during vegetative phase and 200 mm during reproductive phase to obtain the best yield. The relation of rainfall and the yield obtained in Potohar zone is 57%.

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