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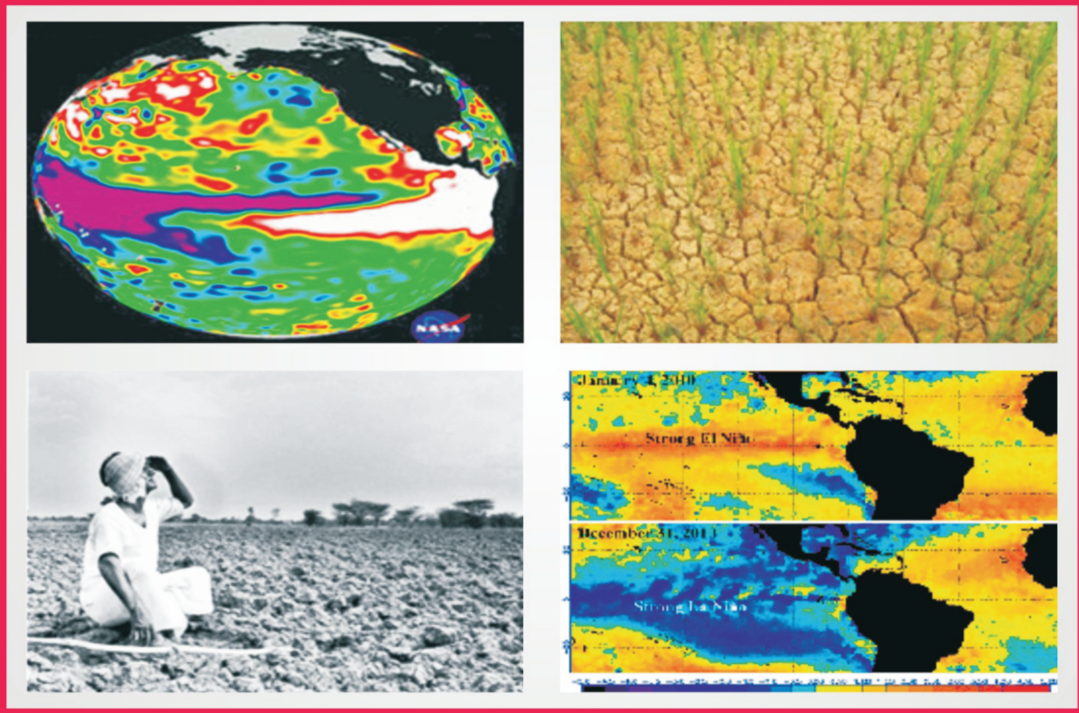
El Niño-Its Impact on Rainfall and Crop Productivity:

A Case Study for Himachal Pradesh



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CSK HPKV, Palampur-176 062, H.P., India

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Front Cover (clockwise): The 1997 El Niño seen by TOPEX/Poseidon, Drought affected rice field, Departure of surface temperature from average (°C), Farmer gazing the sky for arrival of monsoon

Back Cover: Popular tea gardens of Kangra valley

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FOREWORD

National food security in the backdrop of climate variability is a matter of concern for everyone in the society. In a fast growing Indian economy, the contribution from farm sector is declining constantly from 57 per cent in 1950-51 to 13.7 per cent in 2012-13. This decline have a direct impact on the employment opportunities and livelihoods in rural areas. Extreme weather conditions such as floods, droughts, heat and cold waves, cyclones and hail storms cause huge losses to crop production, but even more subtle aberrations in weather during critical phases of crop can also have a substantial impact on the ultimate farm yield. Some of these aberrations may go unnoticed on a regional scale but the science of Agricultural Meteorology has established that the performance of southwest monsoon in the country has a tele-link with El Niño phenomenon.

The information on the anticipated fluctuations in monsoon rainfall and resultant agricultural production prior to the start of growing season has wider implications on decision making at the farm and policy levels.The inter-annual variability of Indian monsoon rainfall has profound influence on agriculture and national economy. Occurrences of droughts and floods associated with the inter-annual variability of Indian monsoon affects the agriculture, water resources and even price rise. This inter-annual variability of Indian monsoon is largely affected by the occurrence of El Niño episodes. A strong El Niño can cause drought like conditions. About 60 per cent of net sown area of the country is rain fed. With every one per cent deficit in rains, the country's gross domestic product falls by 0.35 per cent.

Regional scenarios anticipated in the event of El Niño help the administration to mobilize resources and inputs like seeds, fertilizers etc accordingly. An attempt has been made to examine the possibility of using El Niño as a signal of climatic variability which can help in moderating any likely adverse effects on crop production with better planning and management. There is an urgent need to carry out analogous studies for all those regions where the impact of climatic variability on crop production is significant.

Himachal Pradesh receives rainfall mainly through SW monsoon which is likely to be affected by El Niño event and so the crop production. The relationship between El Niño and its associated influence on rainfall of Himachal Pradesh and agricultural production has not been established so far. The work on this aspect has been undertaken by the Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur. The efforts of the team of All India Coordinated Research Project on Agrometeorology of CSK HPKV, Palampur in bring out this bulletin on "El Niño- Its Impact on Rainfall and Crop Productivity: A Case Study for Himachal Pradesh" are really praise-worthy. I congratulate them and hope that this publication will be of immense use to scientists, farmers and planners.

Prof. K.K. Katoch
Vice Chancellor

Palampur 01 NOV 2014.

SUMMARY

El Niño is fundamentally a warming of the surface waters of the tropical eastern Pacific Ocean from South American coast to the International Date Line that persists for three or more seasons. El Niño is a pervasive climatic phenomenon which was found to be associated with regional climatic variations throughout the world.

Analyses of long term data suggest an inverse relationship between El Niño and southwest monsoon rainfall in India. However, there is no one to one relationship as El Niño years have not always produced severe droughts. More over studies on the effect of El Niño either on crop production or productivity at regional level were not carried out in India so far.

Therefore, an attempt has been made to examine the effect of El Niño for

- identifying changes in seasonal rainfall as well as annual rainfall in different districts of Himachal Pradesh,
- assessing the changes in cereal grain production as well as productivity of some of the crops *viz*., maize, rice, wheat and barley and oilseed crops *viz*., sesame, rapeseed & mustard and linseed,
- suggesting the possible strategies to enhance agricultural production in the event of rainfall anomalies.

The study brought out some of the interesting findings as detailed below:

- Average rainfall during the years with El Niño was not only lower but also had more likelihood of getting below average rains during southwest monsoon. Rainfall deficiency during the monsoon increased with the severity of El Niño.
- Average rainfall during years with El Niño was not only higher but also had more likelihood of getting above average rains during subsequent winter. Rainfall during the winter season was higher in 9 out of 10 selected districts of the state, six districts showed more than 20% increase in rainfall.
- Loss in production or productivity of maize was 12 per cent. Loss in productivity of rice was found to be lower than that of maize.
- Higher rainfall received during winter benefitted wheat and barley.
- Production of four cereal grains (maize, rice, wheat and barley) was unaffected in Una, Hamirpur, Bilaspur and Mandi whereas productivity was unaffected in Mandi and Solan districts only.
- Kullu was the most vulnerable district as far as production is concerned whereas Chamba and Una were the most vulnerable as far as productivity is concerned.
- In Hamirpur district of Himachal Pradesh, the losses in cereal grain productivity were found to be up to 5%.
- Below average rainfall received during southwest monsoon period of an El Niño year reflects into higher chance (60% probability) of getting below average annual rainfall

in the state.

- Since El Niño serves as a strong signal of deficit rainfall for the state, therefore the soil water conservation measures must be followed invariably.

Authors consider that the study may not be very exhaustive and is only intended to enlighten the utility of using signals like El Niño as a possible option to understand climate variability and use it for taking strategic decisions for enhancing agricultural production during seasons with adverse climate to a certain extent.

Although, El Niño phenomena may provide signal only for few of the years, it indicates the possibility to identify some more critical parameters to cover as many years as possible in the near future.

Introduction 1

Agriculture is the principal source of livelihood for more than 58% of the population of this country. In Indian Scenario, agriculture is contributing 13.7% to national GDP. The contribution of agriculture sector in Himachal Pradesh is about Rs. 15,000 crore annually, which is 15% of the state GDP. Agriculture provides bulk of wage goods required by non-agricultural sectors and most of the raw materials for industrial sector. Himachal Pradesh is predominately an agricultural state where agriculture is main source of income as well as employment which provides direct employment to about 71% of the total population. About 18-20% area is irrigated and rest is rain fed (Department of Agriculture, Himachal Pradesh). The main cereals grown in the state are wheat, maize, rice and barley. Kangra, Mandi and to some extent the Paonta valley of Sirmaur district are the major producers of the first three cereals, while barley is mostly cultivated in Shimla (Economy of Himachal by Agriculture).

1.1 ENSO, El Niño & La Niña : The El Niño-Southern Oscillation, or ENSO, is the interannual fluctuation of the atmosphere–ocean system in the equatorial Pacific and it has three phases: warm (El Niño), cold (La Niña), and Neutral. Although El Niño is considered the warm phase of ENSO and La Niña the cold phase, they are not considered opposites because they occur with differing magnitudes, spatial extent and duration.

El Niño is a phenomenon during which an unusually warm water appears in the eastern Pacific Ocean off the coasts of Peru and Ecuador. Because the warm current usually appears around Christmas time, the fishermen named it El Niño, Spanish for "the Christ Child." During La Niña, Spanish for "little girl," unusually cold water is present in these locations, causing contrasting shifts in local weather patterns as well as in the global climate. Anomalous weather patterns in La Niña seasons are generally opposite from those in El Niño. These changes in the surface water temperatures are linked to changes in the strength of the trade winds blowing from east to west across the region. Neutral conditions occur when neither El Niño nor La Niña is present (Fig1).

El Niños and La Niñas occur semi-regularly at intervals of

2-5 years and usually last from 9 to 12 months. Large pools of warm or cold water produced in these events change atmospheric pressure patterns in the tropical Pacific region and global wind patterns far from the tropics. This leads to statistically observable changes in temperature and rainfall patterns that vary by ENSO phase in many areas of the world.

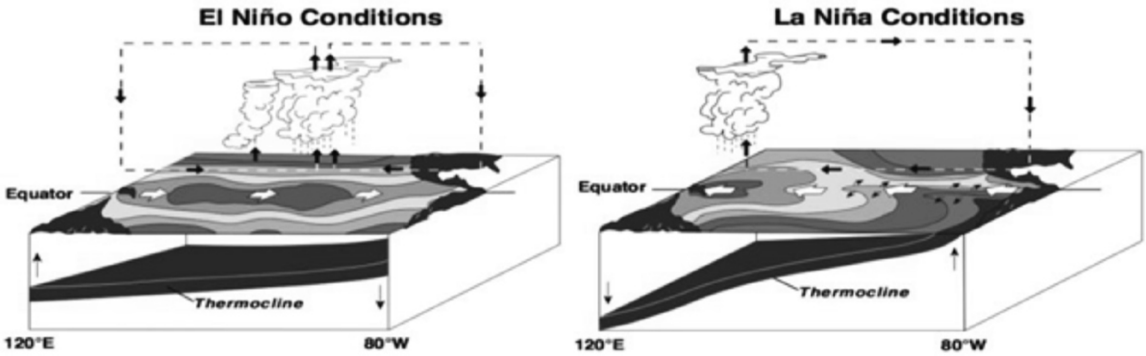

Figure 1. Water temperature and ocean conditions in the Pacific during El Niño (left) and La Niña (right) (NOAA)

Impact of El Niño on rainfall : El Niño affects rainfall in India during monsoon. Due to more heating, warm waters off eastern coast of South America increase sea surface temperatures above normal by 0.5°C and leads to diversion of flow of moist winds from the Indian Ocean towards the eastern coast of South America. This change in wind pattern reduces the amount of rainfall in the Indian sub-continent.

El Niño and the Indian summer monsoon are inversely related. The most prominent droughts in India-six of them - since 1871 have been El Niño droughts, including the recent ones in 2002 and 2009.

It is, however, important to note that not all El Niño years lead to drought in India. For instance, 1997-98 was a strong El Niño year but that did not cause drought in India. On the other hand, a moderate El Niño in 2002 resulted in one of the worst droughts in India.

According to historical data of 126 years (1880-2005), about 90% of all evolving El Niño years have led to below normal rainfall and 65% of evolving El Niño years have brought droughts. However, one thing is clear that El Niño years do affect the weather in India in terms of monsoon rain. During this time, the rainfall is generally below normal, which has its bearing on crop production.

1.2 El Niño episodes and South-West monsoon rainfall : India receives about 1180 mm of rainfall annually. The rainfall over India has a large spatial as well as temporal variability. Normal monsoon rainfall of more than 150 cm is observed over most parts of north east India, Konkan & Goa. Normal monsoon rainfall is more than 4000 mm over major parts of Meghalaya. For the country as a whole, mean monthly rainfall during July (286 mm) is highest and accounts for 24.2% of annual rainfall. The mean rainfall during August is slightly lower and amounts to 21.2% of annual rainfall. June and September rainfall are almost similar and contribute 13.8% and 14.2% of annual rainfall, respectively. The mean South-West monsoon (June, July, August & September) rainfall (877 mm) contributes 74.2% of annual rainfall. Contribution of pre-monsoon (March, April & May) rainfall and post-monsoon (October, November & December) rainfall in annual rainfall is almost similar (11%). Coefficient of variation is higher during the months of November, December, January and February.

The state of Himachal Pradesh is broadly divided into three physio-geographical regions, *viz*., Outer Himalaya, the Lesser Himalaya and the Greater Himalaya or the Alpines. The Outer Himalaya includes the districts of Bilaspur, Hamirpur, Kangra, Una and the lower parts of Mandi, Sirmaur and Solan. The Lesser Himalaya includes the parts of Mandi, Sirmaur and parts of Chamba, Kangra and Shimla districts. The Alpine zone is at an altitude of 4,500 m and beyond, includes Kinnaur and parts of Lahaul and Spiti, Chamba districts. Areas of the state increase in elevation from west to east and from south to north. Among different zones of the state, there is a large variation in rainfall amounts. For instance, first zone receives annual rainfall between 1500 mm to 1750 mm. In second zone, it varies between 750 mm to 1000 mm and the Alpine zone receives solid precipitation during winters only and remains under the impact of snow for about five to six months of the year. Average annual rainfall in the state is about 1600 mm. Climate varies between hot and humid in the valley areas to freezing cold in the areas of perpetual snow (Anonymous, 2012).

1.3 El Niño episodes and Indian food grain production : In a recent study, El Niño episodes were found to improve the global mean soybean yield by 2.1 to 5.4 per cent but, appears to change the yields of maize, rice and wheat by -4.3 to +0.8% (Iizumi *et al.*, 2014). In an earlier study, Selvaraju (2003) observed that during the warm El Niño southern oscillation (ENSO) phase, the total Indian food grain production frequently decreased (12 out of 13 years) by 1 to 15 per cent during 1950-1999 period. The relationship between the SST-based NINO3 ENSO index and *kharif* season (June–September) food grain production anomalies was greater than for *rabi* season (October–February) food grain production. The ENSO impact on rice production was greatest. The average drop in rice (*kharif* season crop) production during a warm ENSO-phase year was 3.4 million tonnes (7%). In a cold ENSO-phase year, the average production increase was 1.3 million tonnes (3%). Wheat production was also influenced by ENSO, as it depends on carry over soil water storage from *kharif* season. Sorghum and chickpea production were found to be not significantly influenced by ENSO extremes.

The above review suggests that during El Niño years there is a large spatial variability in rainfall distribution in the country as well as productivity of different crops. In the light of India Meteorological Department's forecast of a 60% probable El Niño episode during the current year (2014) along with a below normal monsoon projection, we felt that it is apt to analyse rainfall pattern and agricultural productivity in Himachal Pradesh in relation to the El Niño episodes.

2 Methodology

2.1 Rainfall data : The district-wise monthly rainfall data for ten selected districts *viz*., Bilaspur, Chamba, Hamirpur, Kangra, Kullu, Sirmaur, Solan, Shimla, Una and Mandi of Himachal Pradesh recorded during the years 1971-2009, as available in the database at CSK HPKV, Palampur were used in the present study.

The rainfall totals for the southwest monsoon (June-September) and winter (October-May) seasons were aggregated year wise for all the districts of the state.

According to Jan Null (2011), the Oceanic Niño Index (ONI) has become the *de-facto* standard that NOAA uses for identifying El Niño (Warm) and La Niña (Cool) events in the tropical Pacific for the Nino 3.4 region (*i.e*., 5°N to 5°6, 120°-170°W). Events are defined as five consecutive months at or above the +0.5°C anomaly for warm (El Niño) events. The threshold is further broken down into weak with a 0.5 to 0.9°C sea surface temperature anomaly, moderate (1.0 to 1.4°C) and strong (1.5°C) events.

The El Niño years were classified into weak (0.5 to 0.9°C), moderate (1.0 to 1.4°C) and strong (above 1.5°C), based on the threshold values that persisted for at least three months and group the rainfall years accordingly (Table 1). The rainfall years were then categorized as years with non El Niño years (normal rainfall), weak El Niño years, moderate El Niño years and strong El Niño years. During year 1971 to 2009 there were 4 weak El Niño years, 4 moderate El Niño years and 5 strong El Niño years. The mean rainfall for different El Niño years and years with normal rainfall for each district were deduced by averaging the corresponding rainfall data.

Table 1. Classification of El Niño years based on SST anomaly

Intensity	Years
Weak	1976, 1977, 2004, 2006
Moderate	1986, 1987, 1994, 2002
Strong	1972, 1982, 1991, 1997, 2009
Non El Niño	Remaining 26 years (years with normal rainfall)

2.2 Crop data : The area, production and productivity of rice, maize, wheat and barley in different districts of Himachal Pradesh for the years 1981 to 2009 were obtained from Directorate of Agriculture, Shimla.

The time series data on area, production and productivity may feature strong trends that mask seasonal fluctuations likely to be associated with year to year variation in climate. Researchers have isolated these seasonal fluctuations by fitting and removing trends with polynomial and other parametric functions. For example, Parthasarathy *et al*. (1992) employed an exponential function to filter the All India Food grain Production Statistics. Bapuji Rao *et al*. (2014) used a fourth degree polynomial to remove the technology trend in country level paddy yields. We have used anomalies to remove the technology trend in production and productivity of various crops.

3 El Niño Effect on Rainfall

The percentage change in seasonal rainfall during El Niño and non El Niño years was computed for southwest monsoon and winter season in different districts. From Table 2, it can be observed that

- average rainfall during El Niño years in southwest monsoon (June-September) was less than the non El Niño years rainfall in Solan and Mandi by over 20 per cent and Bilaspur and Kullu by over 15 per cent. The decrease in rainfall can be seen in Shimla, Kangra, Una and Sirmaur districts forming low hills and plain areas of the state,
- comparatively, Chamba and Hamirpur districts received higher average rainfall during El Niño years,
- average rainfall during winter season (October-May) was higher than non El Niño years in 9 out of 10 selected districts of the state. The departure was more than 40 per cent in Kullu and Kangra and more than 20 per cent in Una, Sirmaur, Shimla and Bilaspur districts. The increase in rainfall can also be noticed in Hamirpur, Solan and Chamba districts, and
- average rainfall during winter season was higher during El Niño years as compared to non El Niño years' rainfall.

Therefore, it is obvious that compared to non El Niño years' rainfall, the rainfall during El Niño years is likely to be less during southwest monsoon season and more during winter season in most parts of Himachal Pradesh.

Average rainfall for the years with weak, moderate and strong El Niño was calculated and compared with average of non El Niño years for both the seasons and presented in Table 3. It can be seen that

- rainfall deficiency during SW monsoon increased with strength of the El Niño,
- subsequent winter season received higher rainfall hence El Niño has a compensatory effect on winter rains, and
- weak or strong El Niño attracted higher winter rains.

Table 2. Per cent change in average seasonal rainfall (mm) during El Niño years compared to non El Niño years in selected districts of Himachal Pradesh (1971-2009)

District	Southwest monsoon (JUN-SEPT)			Winter (OCT-MAY)		
	El Niño years	Non El Niño years	PC*	El Niño years	Non El Niño years	PC
Bilaspur	753.7	910.7	-17.2	360.8	286.4	26.0
Chamba	610.4	568.7	7.3	603.7	569.5	6.0
Hamirpur	1175.8	1000.5	17.5	324.4	280.0	15.9
Kangra	738.7	808.2	-8.6	248.3	174.4	42.4
Kullu	634.6	753.5	-15.8	336.0	232.8	44.3
Sirmaur	769.4	779.0	-1.2	179.5	138.4	29.7
Solan	691.8	973.8	-29.0	227.5	199.4	14.1
Shimla	696.6	782.9	-11.0	237.7	185.2	28.4
Una	816.9	882.6	-7.4	255.7	185.0	38.2
Mandi	924.6	1194.8	-22.6	371.8	378.9	-1.9

PC*= per cent change

Table 3. Anomalies (%) in seasonal rainfall in different El Niño categories during El Niño years compared to non El Niño years

District	Southwest monsoon (JUN-SEPT)			Winter (OCT-MAY)		
	El Nino Category					
	Weak	Moderate	Strong	Weak	Moderate	Strong
Bilaspur	-22.4	-14.3	-15.5	6.4	2.7	60.4
Chamba	18.7	-10.8	12.7	-14.9	4.8	23.7
Hamirpur	0.1	74.6	-14.2	13.0	12.8	20.6
Kangra	32.2	-29.0	-25.0	61.6	24.8	41.1
Kullu	-0.2	-15.1	-28.8	60.6	21.4	49.6
Sirmaur	56.7	-27.6	-26.5	50.3	22.9	18.7
Solan	-25.6	-25.2	-34.6	10.3	3.5	25.6
Shimla	5.0	-18.6	-17.8	48.7	18.4	20.1
Una	4.5	3.5	-25.8	28.7	30.2	52.3
Mandi	-27.1	-15.2	-25.0	-34.2	11.8	13.1

The percentage change in average annual rainfall during the El Niño years compared to non El Niño years in selected districts of Himachal Pradesh is given in Table 4. The average annual rainfall during El Niño years is less than the years with non El Niño years by more than15 per cent in Solan and Mandi districts. Some decrease was also noticed in Bilaspur, Shimla and Kullu districts. In Hamirpur district, an increase of over 15 per cent was noticed. Chamba, Sirmaur, Una and Kangra also received some increase in annual rainfall during El Niño years.

Table 4. Per cent change in District-wise average annual rainfall (mm) during El Niño years compared to non El Niño years in Himachal Pradesh (1971-2009)

District	Rainfall (mm)		
	El Niño years	Non El Niño years	Per cent change
Bilaspur	1114.6	1197.1	-6.9
Chamba	1214.1	1138.1	6.7
Hamirpur	1500.2	1280.5	17.2
Kangra	987.0	982.6	0.4
Kullu	970.6	986.4	-1.6
Sirmaur	948.9	917.4	3.4
Solan	919.3	1173.3	-21.6
Shimla	934.3	968.0	-3.5
Una	1072.6	1067.6	0.5
Mandi	1296.4	1573.7	-17.6

The year to year variability of rainfall during the southwest monsoon season for the state is shown in Fig 2. Red colored points indicate the rainfall during the El Niño years. It can be seen

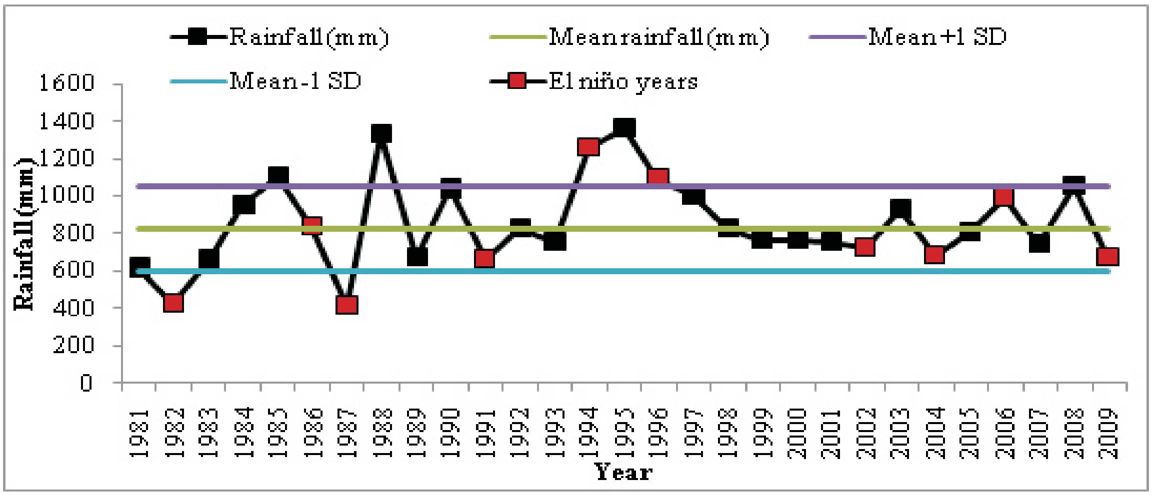

Figure 2. Year-wise average southwest monsoon rainfall (mm) in Himachal Pradesh (1981-2009)

that the rainfall was below normal in 6 out of 10 El Niño years and was above normal in the years 1994, 1996 and 2006. Therefore, the chance of getting below normal rainfall during the El Niño years has a probability of 60 per cent. Two of the deficit rainfall events (1982 and 1987) associated with El Niño experienced a negative departure from normal by more than one standard deviation (SD) of seasonal rainfall, there by indicating impending drought situations likely to occur in association with El Niño.

The year to year variability of rainfall during winter season for the state is shown in Fig 3. It can be seen that the winter rainfall was below normal in only 3 (1987, 1994 and 2009) out of 10 years. Therefore, the chance of getting below normal winter rainfall during El Niño years is only 30 per cent. Conversely, chance for getting above normal rainfall is 70 per cent.

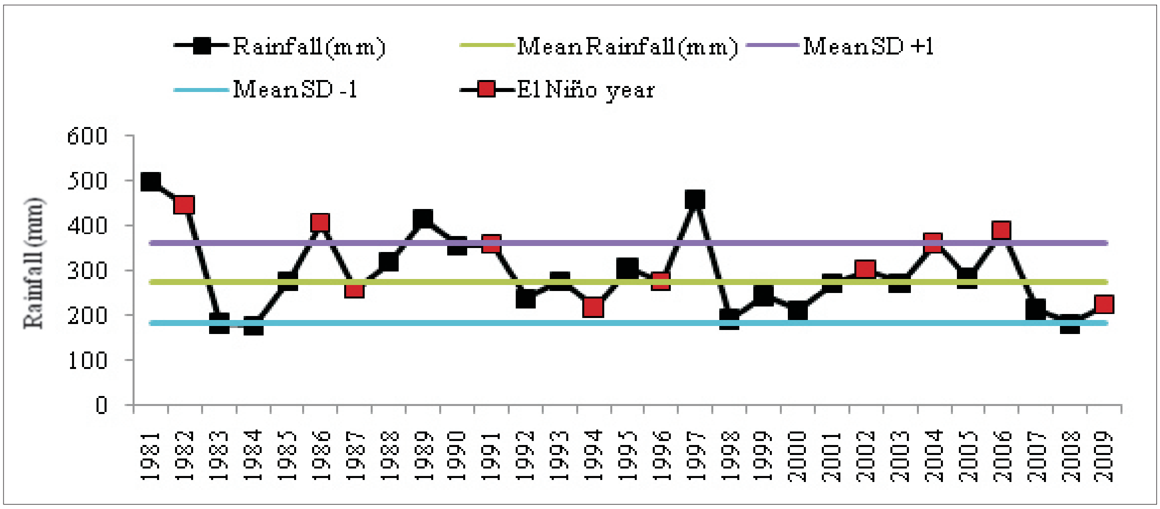

Figure 3. Year-wise winter rainfall (mm) in Himachal Pradesh (1981-2009)

The year wise annual rainfall for the state during the years 1981 to 2009 is shown in Fig 4. It can be seen that the annual rainfall is less than normal in 6 out of 10 years and it was more than

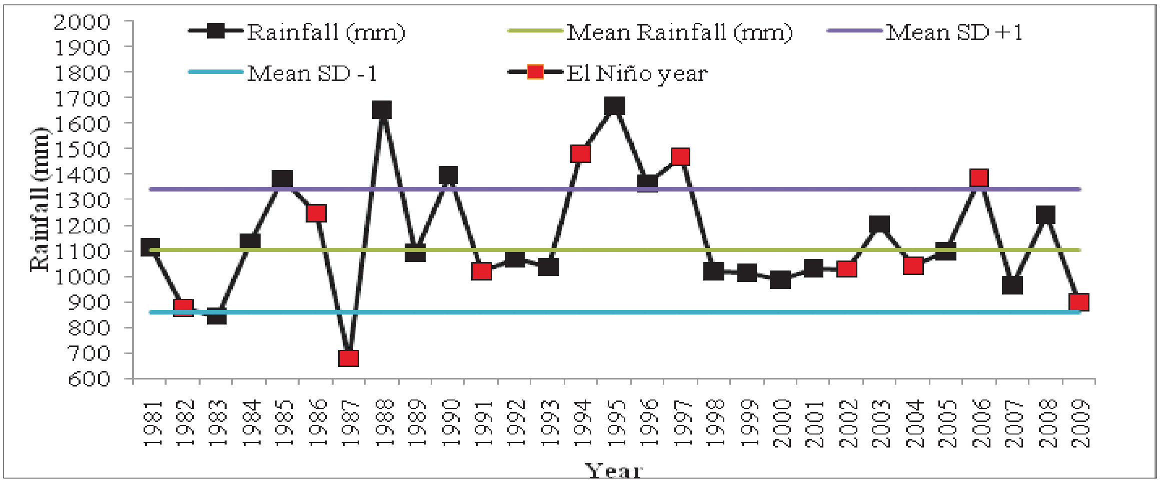

Figure 4. Year-wise average annual rainfall (mm) in Himachal Pradesh (1981-2009)

normal during the four years 1986, 1994, 1997 and 2006. Therefore, annual rainfall can be expected to be above average with 40 per cent probability during El Niño years.

By comparing Fig 2, 3 and 4, it can be observed that

- when the southwest monsoon rainfall was below average during El Niño years, the annual rainfall was also below average in same six years 1982, 1987, 1991, 2002, 2004 and 2009 out of ten El Niño years, and
- southwest monsoon rainfall was average only during one year *viz*., 1986 although the annual rainfall was above average.

Therefore, it may be possible that either the southwest monsoon season rainfall or the annual rainfall is likely to be less than average during El Niño years. Hence, El Niño might serve as a strong signal of deficit rainfall for the state.

Total Cereal Grain Production and Crop Yields 4

The year-wise cereal grain (maize, rice, wheat and barley) production and productivity in the state for the years 1981 to 2009 is shown in Fig 5 & 6, respectively. It is observed that

- the production of above four cereal grains in the state fluctuated between 8.9 million tonnes during1987 to 15.8 million tonnes during 2001, and
- the productivity fluctuated between 1086 kg/ha during 1987 to 1845 kg/ha during 2001.

It is interesting to note that the cereal grain production and productivity in the state during El Niño years was found to be above average in five out of seven El Niño years after 1990. Therefore, there is an obvious signal that the cereal grain production did not decrease during most of the recent El Niño years.

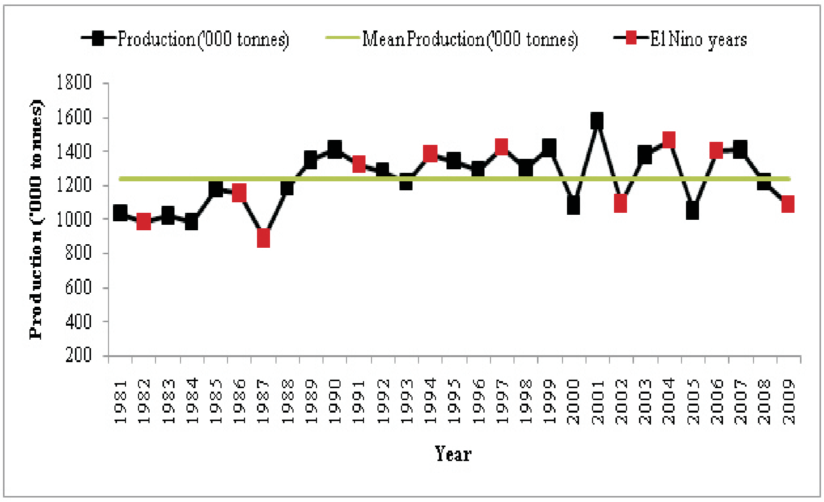

Figure 5. Year-wise cereal grain production ('000 tonnes) in Himachal Pradesh

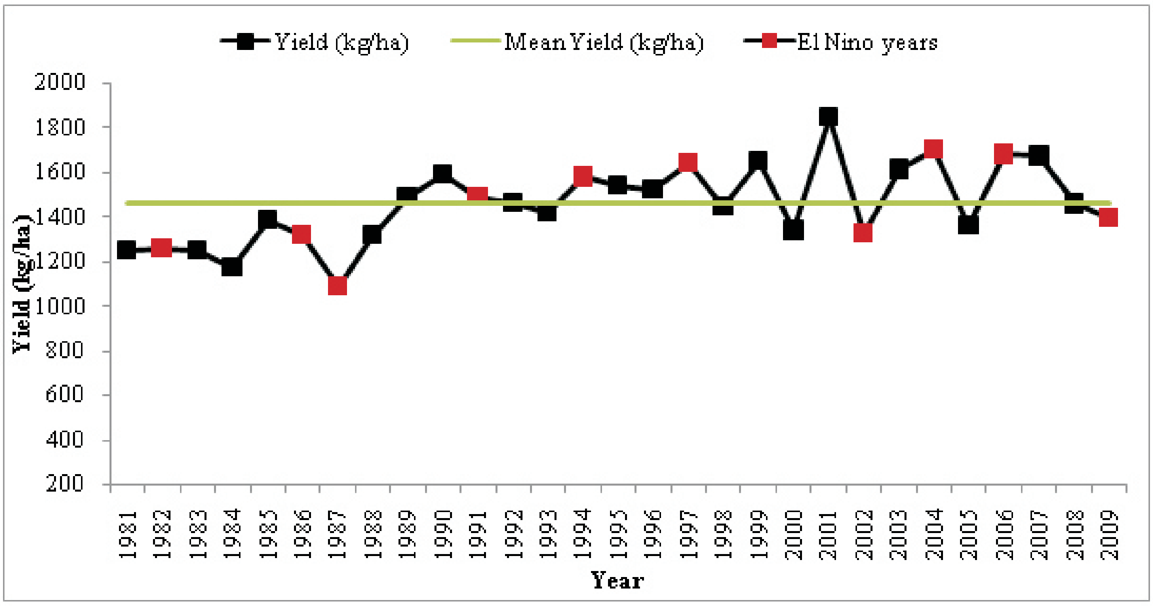

Figure 6. Average productivity (kg/ha) of cereal grains in Himachal Pradesh

District-wise production and productivity of cereal grains : Though El Niño does not suggest the possibility of decline in overall production and productivity of cereal grains in the state, yet the district-wise data were also analyzed to identify the districts which are more vulnerable to El Niño effect. Per cent change in average production during El Niño years compared to the average production in the non El Niño years was calculated for all the districts and is shown in Fig 7. It can be inferred that

- production was not affected in Una, Hamirpur, Bilaspur and Mandi districts,
- production decreased up to 5 per cent in Kangra, Chamba, Lahaul & Spiti, Kinnaur and Solan districts,
- production declined by 5 to 10 per cent in Sirmaur and Solan districts, and
- production dipped by 10 to 15 per cent in Kullu district.

Therefore, an effect of decreasing tendency of the southwest monsoon rainfall on cereal grain production during El Niño years is visible over larger part of the state barring Una, Hamirpur, Bilaspur and Mandi districts.

In general, the tendency is that the regions better served by rainfall associated with western disturbances are comparatively less vulnerable to decline in productivity of wheat and barley during El Niño years as subsequent winter season receives higher rains in the state.

The per cent decline in productivity during the years with El Niño compared to the non El Niño years in different districts of Himachal Pradesh is shown in Fig 8. It can be inferred that

- productivity was not affected in Mandi and Solan districts,
- productivity was affected up to 5 per cent in most of districts *i.e.*, Kangra, Kullu, Lahaul & Spiti, Kinnaur, Shimla, Sirmaur, Bilaspur and Hamirpur, and
- productivity likely to be declined by 5 to 10 per cent in Una and Chamba districts.

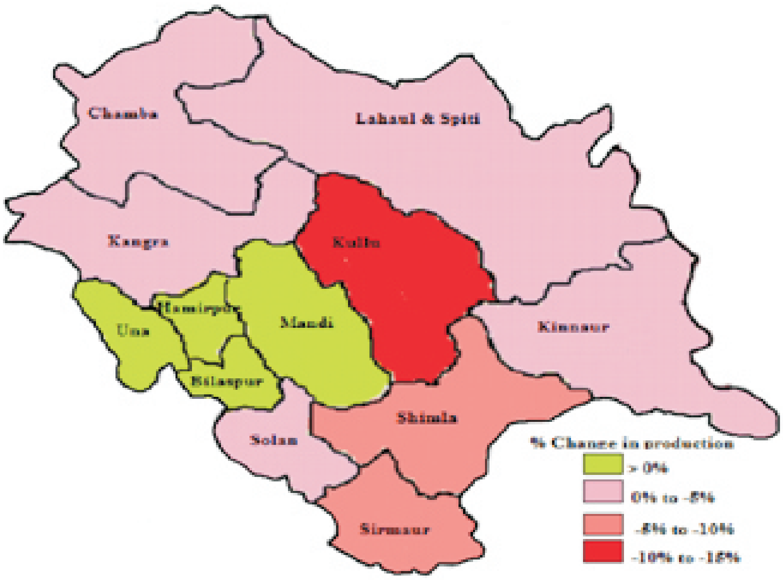

Figure 7. Per cent change in cereal grain production during El Niño years compared to non El Niño years in Himachal Pradesh (1981-2009)

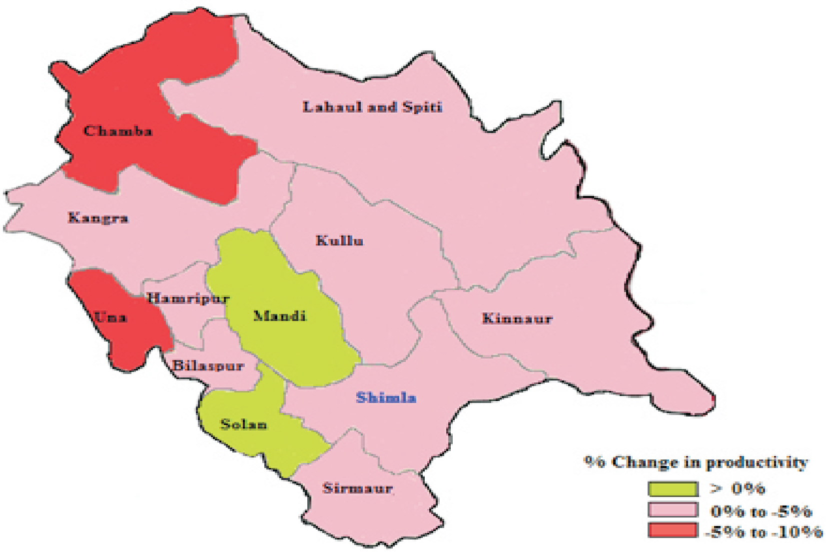

Figure 8. Per cent change in average cereal grain productivity during El Niño years compared to non El Niño years in Himachal Pradesh (1981-2009)

Therefore, the effect of decreasing tendency of the southwest monsoon rainfall on cereal grain productivity during El Niño years is visible on larger part of the state barring Mandi and Solan districts.

Maize

Maize is the most important crop, which ranks 1st in production and 2nd in area after wheat among cereal crops grown in Himachal Pradesh. It is cultivated over an area of 2, 95,000 hectares. Average productivity of this crop is 1839 kg/ha against the national average of 2091 kg/ha (Anonymous, 2011a). The state tops the list of maize producing states in the hill regions of the country with respect to production and has immense potential to increase productivity and production. Maize provides food security to sizeable population of this hill state besides which it is also used as poultry and animal feed.

This crop is one of the most important *kharif* crop of the state and is grown in all the districts of the state. Kangra, Mandi, Hamirpur, Una, Chamba, Bilaspur, Sirmaur, Solan, Shimla and Kullu accounts for over 90 per cent of the area and production of this crop. The district-wise average of area, production and yield of maize during the El Niño years compared to the non El Niño years is given in Table 5. It is observed that

- the production of the maize for the state was highly affected by El Niño,
- the production in the state was declined by 11.9 per cent during El Niño years,
- the reduction in productivity was 19.7 per cent in Kullu, 17.2 per cent L & S and 15.2 per cent in Solan district,
- kullu seems to be the most affected district with respect to production (23.7 per cent) and productivity (19.7 per cent), and
- the average area under maize decreased only marginally (0.8 per cent) in the state during El Niño years but reduction in the area in individual districts varied between 2 to 8.3 per cent. However, the average productivity declined by 12.1 per cent during El Niño years.

Table 5. Per cent change in average area sown ('000 ha), production ('000 tones) and productivity (kg/ha) of maize during El Niño years compared to non El Niño years in Himachal Pradesh (1981-2009)

District	Area			Production			Productivity		
	El Niño	Non El Niño	PC*	El Niño	Non El Niño	PC	El Niño	Non El Niño	PC
Bilaspur	26.2	25.8	1.6	41.0	46.4	-11.6	1558.1	1791.2	-13.0
Chamba	27.6	27.3	1.1	62.8	64.4	-2.4	2268.5	2358.9	-3.8
Hamirpur	32.2	33.0	-2.5	49.2	57.6	-14.5	1523.7	1762.0	-13.5
Kangra	57.0	57.3	-0.6	83.3	97.0	-14.1	1462.4	1690.3	-13.5
Kinnaur	0.396	0.421	-5.8	0.713	0.866	-17.7	1842.9	2082.5	-11.5
Kullu	15.5	16.5	-6.0	31.2	40.9	-23.7	1982.8	2468.2	-19.7
L & S	0.028	0.030	-8.3	0.055	0.066	-15.9	1379.8	1666.3	-17.2
Mandi	45.8	46.8	-2.2	105.2	116.5	-9.7	2273.3	2472.2	-8.0
Shimla	17.4	18.4	-5.8	32.9	40.0	-17.9	1915.0	2194.1	-12.7
Sirmaur	24.3	24.8	-2.2	54.8	64.7	-15.3	2275.3	2618.1	-13.1
Solan	24.5	24.3	0.8	43.8	51.4	-14.6	1791.9	2111.9	-15.2
Una	30.5	29.1	4.6	51.6	51.8	-0.3	1689.3	1770.5	-4.6
H.P.	301.3	303.9	-0.8	556.8	631.6	-11.9	1830.3	2082.2	-12.1

PC*=per cent change

The change in maize productivity during different El Niño years is presented in Table 6. It could be noticed that

- weak El Niño years influenced positively affected the maize yield of L&S, Una, Mandi, Hamirpur and Bilaspur districts, and
- maize productivity during moderate & strong El Niño years appears to be more negatively

influenced compared to weak El Niño years.

Table 6. Anomalies (%) in maize productivity during El Niño years compared to non El Niño years in maize growing districts

District	El Niño category			
	Weak	Moderate	Strong	Combined
Bilaspur	13.5	-20.1	-19.2	-13.0
Chamba	7.6	-6.6	-6.8	-3.8
Hamirpur	14.7	-19.6	-21.6	-13.5
Kangra	-6.1	-20.6	-10.1	-13.5
Kinnaur	7.0	-17.3	-15.0	-11.5
Kullu	7.8	-29.1	-24.0	-19.7
L & S	33.6	-45.2	-14.6	-17.2
Mandi	18.2	-13.4	-15.8	-8.0
Shimla	-2.5	-13.7	-16.8	-12.7
Sirmaur	1.4	-19.0	-14.4	-13.1
Solan	-7.0	-17.7	-16.7	-15.2
Una	20.6	-15.9	-5.8	-4.6
H.P.	8.5	-19.3	-15.2	-12.1

Rice

Rice is also one of the most important *kharif* crop of the state. With respect to area and production this crop is an important crop next to maize. Rice is cultivated in ten out of twelve districts of the state except Kinnaur and Lahaul & Spiti and occupies about 78,570 ha with a production and productivity of 1,21,450 tonnes and 1550 kg/ha (Anonymous, 2011a). Kangra and Mandi districts account for about two third of rice area and production in the state. These districts together with Sirmaur and Solan account for over 80 per cent of the area and production under rice. There is a great diversity of agro-climatic conditions under which rice is cultivated and its cultivation extends from foot-hills (350 m) to high hills (up to 2300 m).The district- wise average of area, production and productivity of rice during the El Niño years compared to the remaining years is given in Table 7.

It is observed that

- Kangra and Mandi districts having largest acreage under rice, productivity was affected only by about 8.4 and 4 per cent respectively,
- reduction in yield was 13.2 per cent in Chamba and 12.8 per cent in Hamirpur districts but the area in these districts is quite low, and
- average area under rice decreased by less than 1 per cent but the production and productivity decreased by 5.4 and 4.5 per cent in the state during El Niño years.

Table 7. Per cent change in average area sown ('000 ha), production ('000 tonnes) and productivity (kg/ha) of rice during El Nino years compared to non El Niño years in Himachal Pradesh (1981-2009)

District	Area			Production			Productivity		
	El Niño	Non El Niño	PC*	El Niño	Non El Niño	PC	El Niño	Non El Niño	PC
Bilaspur	2.4	2.5	-2.2	2.65	3.02	-12.5	1152.7	1321.7	-12.8
Chamba	3.0	2.9	3.0	4.09	4.00	2.3	1376.9	1383.2	-0.5
Hamirpur	3.375	3.263	3.4	3.44	3.88	-11.3	1076.1	1239.6	-13.2
Kangra	37.6	37.4	0.5	46.08	50.20	-8.2	1230.7	1343.4	-8.4
Kinnaur	0.0276	0.0258	6.9	0.0337	0.0339	-0.7	1249.7	1330.9	-6.1
Kullu	2.190	2.155	1.6	2.90	2.86	1.1	1344.0	1327.1	1.3
Mandi	22.4	22.2	0.6	27.04	27.84	-2.9	1219.3	1269.9	-4.0
Shimla	3.2	3.4	-6.0	3.59	3.91	-8.3	1111.5	1136.8	-2.2
Sirmaur	5.153	5.217	-1.2	7.27	8.09	-10.1	1409.9	1541.3	-8.5
Solan	4.3	4.1	4.8	7.05	6.48	8.7	1630.3	1586.0	2.8
Una	2.1	2.0	3.2	3.50	3.47	0.8	1631.0	1638.5	-0.5
H.P.	85.7	85.2	0.6	107.6	113.8	-5.4	1202.7	1259.9	-4.5

PC*=per cent change

The change in rice productivity during different El Niño years is presented in Table 8. It could be noticed that

- weak El Niño years positively affected the rice productivity of all the districts except Hamirpur district, and
- productivity of rice was more negatively influenced by moderate El Niño as compared to weak or strong El Niño.

Table 8. Anomalies (%) in rice productivity during El Niño years compared to non El Niño years in major rice growing districts

District	El Niño category			
	Weak	Moderate	Strong	Combined
Bilaspur	3.0	-44.0	10.5	-12.8
Hamirpur	-15.7	-27.8	2.6	-13.2
Kangra	0.2	-20.6	-0.5	-8.4
Kinnaur	5.0	-14.1	-3.7	-6.1
Solan	43.8	-17.2	2.3	2.8
Una	4.0	-13.0	9.9	-0.5
H.P.	4.8	-13.8	0.1	-4.5

Wheat

Wheat is another important *rabi* crop of the state and it covers about 3, 66,590 ha area. Average productivity of this crop is 1533 kg/ha against the national average of 2802 kg/ha (Anonymous, 2011b). This crop is grown in almost all the districts of the state. The main districts where wheat is grown are Kangra, Mandi, Hamirpur, Una, Sirmaur, Bilaspur, Shimla, Solan, Kullu and Chamba which account for over 99 per cent of the area and production under wheat.

The district- wise average of area, production and productivity of wheat during the El Niño years compared to the non El Niño years is given in Table 9.

The main findings emerging from Table 9 are:

- except in one or two districts, productivity of the wheat for the state is positively influenced during El Niño year,
- productivity of wheat increased by 18.6 per cent in Chamba district compared to non El Niño year, wherein only 19,000 ha area is covered under this crop,
- increase in the production and productivity in two major districts *viz*., Kangra and Mandi was 9.5 and 8.8 per cent and 15.2 and 14.5 per cent respectively,
- per cent increase in productivity was 29 per cent in Hamirpur, 24.4 per cent in Bilaspur and 13.3 per cent in Solan districts during El Niño year as compared to non El Niño year,
- similar increase in productivity but of smaller magnitude was also observed in the remaining districts, and
- average area and productivity showed a positive change by 10.9 and 7.0 per cent during El Niño years.

Table 9. Per cent change in average area sown ('000 ha), production ('000 tonnes) and productivity (kg/ha) of wheat during El Niño years compared to non El Niño years in Himachal Pradesh (1981-2009)

District	Area			Production			Productivity		
	El Niño	Non El Niño	PC*	El Niño	Non El Niño	PC	El Niño	Non El Niño	PC
Bilaspur	26.7	26.9	-0.8	38.9	31.3	24.0	1444.2	1160.7	24.4
Chamba	19.6	19.2	1.9	25.3	24.4	4.0	1290.3	1586.0	-18.6
Hamirpur	35.1	35.0	0.4	44.8	34.7	29.3	1279.7	991.9	29.0
Kangra	91.6	90.9	0.7	131.1	119.7	9.5	1426.1	1310.9	8.8
Kinnaur	0.635	0.659	-3.7	0.716	0.754	-5.1	1282.9	1324.0	-3.1
Kullu	21.2	22.6	-6.2	36.3	38.2	-5.2	1691.1	1691.8	0.0
L & S	0.097	0.119	-18.5	0.154	0.163	-5.6	1091.9	984.4	10.9
Mandi	66.4	66.3	0.2	94.4	82.0	15.2	1417.6	1238.1	14.5
Shimla	23.3	24.1	-3.6	27.1	27.5	-1.2	1185.6	1121.1	5.8
Sirmaur	27.8	28.2	-1.1	41.7	37.4	11.4	1499.3	1331.5	12.6
Solan	23.6	23.8	-0.9	33.6	30.0	12.1	1414.7	1249.0	13.3
Una	32.5	31.4	3.3	47.6	44.3	7.5	1465.6	1417.7	3.4
H.P.	368.6	369.3	-0.2	521.7	470.4	10.9	1374.1	1283.9	7.0

PC*=per cent change

The change in wheat productivity during different El Niño years are presented in Table 10. It can be seen that

- productivity of wheat was negatively influenced by moderate El Niño years as compared to weak or strong El Niño years, and
- Chamba was the most affected district of the state during moderate El Niño year.

Table 10. Anomalies (%) in wheat productivity during El Niño years compared to non El Niño years in wheat growing districts

District	El Niño category			
	Weak	Moderate	Strong	Combined
Bilaspur	87.6	-13.7	31.0	24.4
Chamba	-4.3	-26.3	-18.2	-18.6
Hamirpur	88.7	6.1	22.1	29.0
Kangra	28.5	3.1	4.6	8.8
Kinnaur	22.0	-20.6	1.9	-3.1
L & S	78.2	-24.8	13.1	10.9
Mandi	34.5	5.7	13.2	14.5
Shimla	10.3	-0.5	9.7	5.8
Sirmaur	28.6	2.8	14.5	12.6
Solan	52.1	-8.8	15.9	13.3
Una	-0.3	-1.6	10.2	3.4
H.P.	32.0	-6.4	7.9	7.0

Barley

Barley is second most important *rabi* crop of the state after wheat, grown in all the districts of the state, covering an average area of 23,510 ha. Average productivity of this crop is 1300 kg/ha against the national average of 1021 kg/ha (Anonymous, 2011b). Shimla, Mandi, Chamba, Kullu, Kangra, Sirmaur are the main districts where barley is grown. The district-wise average of area, production and productivity of barley during the El Niño years as compared to non El Niño years is given in Table11.

It is observed that :

- the influence of El Niño on barley productivity was positive in all the districts, except for district Chamba and Una,
- the productivity of barley crop was influenced negatively to the extent of 4.3 and 33.9 percent in Chamba and Una districts, respectively. The area under barley cultivation in Chamba and Una is 4100 ha and 12 ha, respectively,
- increase in production and productivity of 8.8 and 13.4 per cent was observed in Shimla district, while Mandi district witnessed the increase of the order of 14.2 and 14.5 per cent,
- per cent increase in productivity was 29.2 per cent in Solan and 11.5 per cent in Kinnaur district,
- similar increase in productivity but with smaller magnitude was also observed in the remaining districts, and
- the average area and productivity showed a positive change by 6.3 per cent each during El Niño years.

Table 11. Per cent change in average area sown ('000 ha), production ('000 tonnes) and productivity (kg/ha) of barley during El Niño years compared to non El Niño years in Himachal Pradesh (1981-2009)

District	Area			Production			Productivity		
	El Niño	Non El Niño	PC*	El Niño	Non El Niño	PC	El Niño	Non El Niño	PC
Bilaspur	0.361	0.344	5.1	0.446	0.408	9.2	1258.2	1165.6	7.9
Chamba	4.0	4.1	-3.6	4.3	4.7	-8.4	1087.3	1136.1	-4.3
Hamirpur	0.140	0.157	-11.1	0.174	0.184	-5.6	1259.9	1165.3	8.1
Kangra	2.9	3.1	-4.3	3.417	3.420	-0.1	1183.5	1133.3	4.4
Kinnaur	1.4	1.5	-4.5	2.1	1.9	8.3	1486.4	1333.3	11.5
Kullu	3.625	3.649	-0.7	5.5	5.0	9.4	1528.8	1399.8	9.2
L & S	0.416	0.464	-10.4	0.556	0.560	-0.7	931.0	884.7	5.2
Mandi	4.4	4.3	0.9	6.2	5.4	14.2	1429.5	1248.2	14.5
Shimla	5.2	5.3	-2.9	6.6	6.1	8.8	1267.5	1117.7	13.4
Sirmaur	2.6	2.7	-4.2	2.8	2.7	1.8	1052.8	981.4	7.3
Solan	1.8	1.7	1.8	2.0	1.5	29.9	1100.5	851.7	29.2
Una	0.012	0.032	-63.1	0.015	0.042	-64.9	635.0	961.0	-33.9
H.P.	26.9	27.5	-2.3	34.0	32.0	6.3	1185.0	1114.8	6.3

PC*=per cent change

The change in barley productivity during different El Niño years is presented in Table 12. It can be seen that

- productivity of barley was more negatively influenced by moderate El Niño years as compared to weak or strong El Niño years,
- Chamba was the most affected district of the state, and
- Solan having only 180 ha area was highly and positively benefitted district due to El Niño.

Thus productivity of wheat and barley was more negatively influenced during moderate El Niño years.

Table 12. Anomalies (%) in barley productivity during El Niño years compared to non El Niño years in barley growing districts

District	El Niño category			
	Weak	Moderate	Strong	Combined
Bilaspur	21.9	-0.3	9.2	7.9
Chamba	19.9	-13.3	-7.4	-4.3
Hamirpur	22.5	-0.3	9.4	8.1
Kangra	22.2	-4.7	4.7	4.4
Kinnaur	37.7	-5.1	14.9	11.5
L & S	60.8	-25.7	8.4	5.2

Mandi	32.6	6.7	13.3	14.5
Shimla	7.7	0.003	29.6	13.4
Sirmaur	27.2	-5.8	10.4	7.3
Solan	41.6	25.3	26.9	29.2
H.P.	17.9	-3.5	10.3	6.3

Oilseed crops

In Himachal Pradesh, the major oilseed crops (sesame, rapeseed-mustard and linseed) are grown over an area of 13 thousand hectares of which nearly 74.6 per cent area is occupied by *rabi* oilseed crops *viz*., rapeseed-mustard and linseed. Sesame is one of the most important *kharif* oilseed crop in the state. It is grown over an area of 3.59 thousand hectares with a total production of 1.27 thousand metric tonnes and productivity 0.35 tonnes/hectare (Statistical Outline of Himachal Pradesh, 2009-10). The crop accounts for 27.7 per cent area under total oilseeds and contributes to about 29.2 per cent to the total oilseeds production in the state. Though, the crop is grown in all the districts except Kinnaur, Kullu and Lahaul & Spiti yet, Kangra alone contributes about 70 per cent to the total sesame production in the state. The crop is cultivated as a pure rain fed crop or mixed crop with maize, black gram or horse gram during *kharif* season.

Rapeseed-mustard group of crops are grown over an area of 9 thousand hectares with a total production of 2.4 thousand metric tonnes and productivity 267 kg/ha (Anonymous, 2012). These crops are raised as sole or mixed/inter- crops with wheat mostly under rain fed conditions. Linseed is grown both on prepared beds as well as under 'Utera' system-a cultivation method in which the seed of linseed crop is broadcasted in moist rice fields before rice harvest. Over the last ten years (1998-99 to 2007-08), rapeseed-mustard and linseed crops have accounted for 59.8 and 12.5 per cent area under total oilseeds and contributed about 63.8 and 7.0 per cent to the total oilseed production in the state, respectively.

The average of area, production and productivity of oilseed crops during the El Niño years compared to non El Niño years is given in Table 13.

Table 13. Per cent change in average area sown ('000 ha), production ('000 tonnes) and productivity (kg/ha) of oilseed crops during El Niño years compared to Non El Niño years in Himachal Pradesh (1981-2007)

Crops	**Area**			**Production**			**Productivity**		
	El Niño	**Non El Niño**	**PC***	**El Niño**	**Non El Niño**	**PC**	**El Niño**	**Non El Niño**	**PC**
Sesame	6.2	5.9	5.1	1.7	1.9	-10.5	310.6	347.2	-10.5
Rapeseed & mustard	8.5	8.2	3.7	3.3	2.9	13.8	372	344.4	8.0
Linseed	3.4	3.5	-2.9	0.9	0.97	-10.0	275.8	272.9	1.1

PC*=per cent change

It is observed that

- influence of El Niño on sesame production and productivity was negative in the state, though there was some increase in the area under this crop,
- area, production and productivity of rapeseed and mustard was positively influenced by an extent of 8, 13.8 and 3.7 per cent, respectively, and
- a marginal increase in productivity was also noticed in linseed during El Niño years.

The change in oilseed crops productivity during different El Niño years is presented in Table14.

Table 14. Anomalies (%) in crop productivity of oilseed crops during El Niño years compared to non El Niño years in Himachal Pradesh

El Niño category			
Weak	**Moderate**	**Strong**	**Combined**
Sesame			
31.0	-37.3	-2.6	-10.5
Rapeseed & Mustard			
42.1	-2.7	-0.4	8.0
Linseed			
-5.3	-2.2	9.6	1.1

It could be noticed that

- weak El Niño positively affected the sesame and rapeseed & mustard productivity in the state,
- moderate El Niño had more negative influence on sesame as compared to rapeseed & mustard, and
- strong El Niño had more positive influence on linseed than weak or moderate El Niño.

5 Possible Options for Enhancing Crop Production

Reliable weather predictions for a month or so may not be made readily available and until then, there is a need to identify some of the global signals like El Niño, which can be used as a signal to climate variability at least during some of the years.

Our present study indicated that the southwest monsoon rainfall or annual rainfall is likely to decrease with a possibility of increased winter rain in some districts of the state. The following strategies may be useful for enhancing crop production during the El Niño years. Kullu, Chamba, Una, Shimla & Sirmaur districts of the state witnessed higher El Niño impact and require special attention.

- Since the hilly areas of the state are persistently confronted with low air and soil temperature therefore, early as well as timely planting of both during *rabi* and *kharif* season crops could be one prime non-monitory input for enhancing the crop productivity.
- As southwest monsoon rainfall has a tendency to decrease during El Niño years and winter rainfall has a tendency to increase during subsequent years in the state, it is important to advocate inter cropping systems with long duration base crop and medium to short duration companion crop(s).
- Study also points out that the state must be fully geared up to capitalize on a possible good winter rains in the ensuing *rabi* season after the El Niño year but also be ready with *rabi* contingency measures.
- Under the event of late onset of monsoon, maize should not be sown after 15th of July, instead Chari, Bajra etc., should be raised as fodder crops.
- During El Niño years, rice should only be cultivated in areas having assured irrigation facilities or in low lying fields having reasonably large catchment areas. Rice should not be cultivated in truly upland areas during these years.
- After the early withdrawal of monsoon, variety Bhawani a short duration variety of toria or Karan rai, variety Jayanti, a long duration crop can be sown after 20th September in order to proper utilize the soil residual moisture.

- During timely receipt of winter rains, mustard variety RCC-4 can be sown as a pure or mixed crop with wheat during end of October.
- During late receipt of winter rains, short duration varieties of gobhi sarson *viz*., Neelam and Him Sarson-1 with short and sturdy stem can be sown even by 15th November.
- In mid hills, brown sarson varieties KBS-3 / HPBS-1 can be sown as a pure crop both for oil and *saag* (KBS-3) during end of October.
- Under rain fed conditions, better yields can be realized during *rabi* season by adopting *in situ* moisture conservation practices and judicious use of fertilizers with regard to timing and quantum.
- Plantation crops like mango, citrus fruits, apple etc., are likely to yield less during El Niño years, wherever the monsoon rainfall has a tendency to decrease, appropriate moisture conservation practices have to be followed.
- Vegetable production during *kharif* season is likely to get affected and production can be sustained by promoting protective agriculture and use of shade nets. Micro irrigation system especially the sprinkler irrigation needs to be advocated to improve water use efficiency.
- Since there is projections for higher winter rains after El Niño, it is advised that the farmers should complete all their timely wheat sowing between 20th October to 1st week of November. The delay in sowing beyond 1st week of November results in 20-35% reduction in grain yield of wheat.
- Farmers should also go in for early wheat sowing for better utilization of residual soil moisture *i.e*., from 10th to 20th October.
- Use conservation tillage and mulching for proper utilization of stored soil moisture.

As the data considered up till now indicates greater vulnerability of crop production during years with moderate El Niño events, farmers have to be cautioned on the judicious use of limited irrigation water so that the available water can be spared for proper use in larger areas as far as possible.

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