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Trends in climate and productivity and relationship between climatic variables and productivity in black pepper (*Piper nigrum*)

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ABSTRACT

Trend analysis of the climatic parameters (past two decades) in major black pepper growing areas of the country showed in general that rainfall is decreasing while temperature is increasing. Black pepper productivity also showed a decreasing trend. Studies on the relationship between climatic parameters and productivity in black pepper showed that December and January rainfall had negative correlation while April and May rainfall had positive correlation. Minimum temperature had positive correlation in higher elevations while both Tmax and Tmin had negative correlation with productivity in plains. Results on the extent of relationship between climatic parameters and productivity revealed that Tmax and Tmin influenced yield more than rainfall or rainy days. Normalized yield deviations (NYD) were worked out (deviations from the mean for two decades) for different stations based on the climatic data for the past two decades. This was regressed with rainfall, Tmax and Tmin to get regression line which can predict the yield deviations if values for rainfall, Tmax and Tmin are substituted in the equation. However, apart from the weather parameters used for the study, other weather variables such as light and humidity and other factors such as cost of cultivation and price for the produce, diseases and management practices definitely have a role in production and productivity of black pepper.

Key words: Black pepper, Climatic parameters, Rainfall, T max, T min, NYD, Yield

Black pepper (*Piper nigrum* L.) is a plant of humid tropics which requires adequate rainfall and humidity for its growth and development. The crop tolerates a temperature range of 10°-40°C. The ideal temperature is 23° - 32°C with an average of 28°C. Optimum soil temperature for root growth is 26° - 28°C. It successfully grows between 20° North and South latitude and from 1 500 m above MSL (Radhakrishnan *et al.* 2002). A relative humidity of 60–95% is optimum for the crop at various stages of growth. The rainfall requirement of the crop varies from 2 000–3 000 mm. Tropical temperature and high relative humidity with little variation in day length through out the year is relished by the crop. It does not tolerate excessive heat and dryness (Sivaraman *et al.* 1999).

Total rainfall and its distribution play an important role in black pepper cultivation and productivity. Annual rainfall of about 2 000 mm with uniform distribution is ideal. Rainfall of 70 mm received in 20 days during May-June is sufficient for triggering flowering process in the plant, but once the process is set off there should be continuous showers until fruit ripening. Any dry spell even for a few days within this critical period of 16 weeks (flowering to fruit ripening) will result in low yield. In India, black pepper growing areas receive 1 500 mm to more than 4 000 mm rainfall. Rainfall after stress induces profuse flowering. Growth of fruit bearing lateral shoots and photosynthetic rate are maximum during peak monsoon in India (Ravindran *et al.* 2000).

Significant correlation was obtained between rainfall received during first half of May and also with rainfall received during the second half of June and yield (r = 0.90). High dry matter accumulation was observed in branches just before shoot elongation and flowering during April-May (Ravindran *et al.* 2000). The late commencement of south-west monsoon causes a delay in flower initiation of black pepper. Prolonged spell of drought or heavy rains or the sharp and sudden alteration of the two during advanced stage of berry development could lead to spike shedding. Intensive shedding occurs during years in which heavy north-east monsoon showers are received after a spell of dry period after south-west monsoon.

There is no information available on the trends in past climate and productivity of black pepper in different black pepper growing regions of the country. The relationship

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between past climate (mainly rainfall, maximum and minimum temperatures) and productivity which is now gaining lot of importance due to climate change also help us to predict the influence of each of these factors on productivity. Keeping these points in view, the following objectives were framed.

To study the trends of rainfall, maximum and minimum temperatures in major black pepper growing regions of the country based on the data for the past two decades; to study the black pepper productivity trend for the corresponding period in these regions; to study the nature and extent of relationship between rainfall, minimum and maximum temperatures and productivity, and to predict future yield deviations based on the two decades' mean of rainfall, rainy days, maximum and minimum temperatures.

MATERIALS AND METHODS

Black pepper growing states, Kerala, Tamil Nadu and Karnataka were selected for the study and the data were collected during 2005–06. In Kerala, Ambalavayal (Wynad District), Panniyur (Kannur District), Pampadumpara (Idukki District) and Thrissur were selected. In Tamil Nadu, The Nilgiris and Valparai (Coimbatore District) and in Karnataka, Coorg District were selected. The monthly data on rainfall, rainy days, maximum and minimum temperatures for these black pepper growing districts for two decades were collected from the nearby research institutions. The data on the black pepper productivity for the corresponding period for the region was collected from the respective state agri/horticulture department. First degree polynomial equations were used to fit trend lines. Correlation between the climatic parameters and black pepper productivity for the corresponding District was worked out. For working out the extent of relationship between productivity and climatic parameters, eight separate plantations were used. Twelve years data on climatic parameters (rainfall, minimum and maximum temperatures) and the black pepper productivity for the corresponding period was used for the purpose. Yield was used as dependent variable and rainfall, rainy days, Tmax and Tmin were used as independent variables and the extent of relationship between dependent and independent variables was worked out using regression equation. Normalized yield deviations (NYD) were worked out for different stations based on the climatic data for the past two decades. This was regressed with rainfall, Tmax and Tmin to get regression line which can predict the yield deviations if values for rainfall, Tmax and Tmin are substituted in the equation. SPSS package was used for statistical analysis of the data. Though some of the external factors such as price and bearing habit of the vine/variety also contribute to yield deviation to some extent, these factors were not considered in this study as it is very difficult to quantify those deviations.

RESULTS AND DISCUSSION

Trend analysis

The trend for various climatic parameters and black pepper productivity was worked out for different black pepper growing regions based on the data for 2–3 decades and is summarized in Table 1.

Table 1 shows that most of the black pepper growing areas are experiencing reduction in rainfall and increase in temperature. The black pepper productivity is showing a decreasing trend which could be the result of increase in temperature and reduction in rainfall. Supportive evidence comes from the fact that black pepper is mainly grown as a rainfed crop in homestead gardens.

Table 1 Trend analysis of climatic variables and black pepper productivity

Place	Rainfall	Tmax	Tmin	Productivity
Kerala				
Ambalavayal (Wynad district) 1979–2004	Decreasing Y= –16.626X + 2196	Increasing Y= 0.0278X + 26.96	Increasing Y = 0.0501X + 17.08	No change Y= –0.410X + 406.8
Pampadumpara (Idukki district) 1986–2004	Decreasing Y= –2.0596X + 1931.1		Increasing Y= 0.04X + 21.447	Increasing Y = 6.957X + 315.92
Panniyur (Cannanore district) 1974–2004	Decreasing Y= –5.332X + 3518	Increasing Y= 0.01X + 32.85	Increasing Y= 0.0278X + 22.206	Decreasing Y= –5.022X + 291.3
Trichur1980–2004	Decreasing Y= –10.523X + 2868.5	Decreasing Y= –0.013X + 32.28	No trend Y= 0.004X + 23.29	Decreasing Y= –2.162X + 203.11
Tamil Nadu				
Valparai (Coimbatore District) 1976–2004	No trend Y= –0.261X + 5904	No trend Y= 0.0034X + 25.31	Decreasing –0.13X + 18.41	No change Y= 0.865X + 191.97
Nilgiris1980–1992	Increasing Y= 28.56X + 1423.1	Increasing Y= 0.10X + 22.567	Decreasing Y= –0.05X + 14.11	Decreasing Y= –0.824 + 202.6

Nature of relationship

The correlation between black pepper yield and climate parameters was worked out. The climate and black pepper production data for the past two decades (1984 to 2004) from pepper growing areas of the country were used for the purpose. In Ambalavayal (Wynad), December rainfall showed negative correlation with productivity. Tmin during March and January showed significant positive correlation with productivity while Tmax did not show significant correlation. The relation between productivity, and rainfall and temperature during various months is given below in Table 2.

In Nilgiris, rainfall during December and January had negative correlation with black pepper productivity. Number of rainy days during May had positive influence while that of January was negatively correlated. Tmin showed significant positive correlation with pepper productivity during March, April, July, August and October months (Table 3).

In Panniyur (Cannanore District) also, rainfall and Tmax during December showed negative correlation with productivity and Tmin from August to December showed significant negative correlation with productivity while in Trichur, Tmin during January and Tmax during May and July had significant negative influence on productivity. In Pampadumpara (Idukki District), October rainfall was positively correlated while June, July and September rainfall had negative influence on productivity, whereas in Valparai (Coimbatore District) none of the climatic parameters showed significant correlation with productivity.

The correlation between climatic parameters and productivity shows in general that in plains (Trichur and Kannur) Tmin and Tmax had negative influence while in higher elevations (Wynad, Nilgiris, Pampadumpara) Tmin had positive influence on productivity. Tmax does not seem to have much influence on productivity in higher elevations. This implies that climate change especially the increase in minimum temperature could increase productivity in higher elevations while the same could reduce the productivity in plains. Increased rainfall during December and January tend to decrease productivity while April and May rainfall increase the productivity.

Table 2 Relationship between climatic parameters and productivity (1984–2004) at Ambalavayal

Month	Tmax	Tmin	Rainfall
January	0.15	0.46*	–0.04
February	0.14	0.38	0.31
March	–0.07	0.58*	0.23
April	–0.23	0.23	–0.01
May	0.25	0.24	–0.31
June	0.12	0.23	–0.07
July	0.01	0.25	0.23
August	0.10	0.18	0.21
September	0.10	0.17	0.01
October	–0.04	0.12	–0.12
November	0.02	0.21	0.00
December	0.18	0.24	–0.41

*P = 0.05

Table 3 Relationship between climatic parameters and productivity (1984–2004) at Nilgiris

Month	Rainy days	Rainfall	Tmax	Tmin
January	–0.47*	–0.42	0.33	0.01
February	–0.28	–0.25	0.37	0.00
March	0.27	–0.05	0.29	0.50*
April	0.25	0.07	0.32	0.46*
May	0.35	0.10	0.39	0.38
June	0.17	–0.06	0.30	0.35
July	0.20	0.15	0.32	0.48*
August	0.13	–0.01	0.34	0.46*
September	0.25	–0.16	0.35	0.41
October	–0.29	0.04	0.00	0.46*
November	–0.02	–0.17	0.26	0.33
December	–0.24	–0.37	0.26	0.23

*P = 0.05

Extent of relationship

To work out the extent of relationship between climatic parameters and productivity, six different plantations in Coorg were selected. Climatic data of these plantations from 1995 to 2005 and the yield of those plantations for the corresponding period were used to develop regression equations. Results revealed that Tmax and Tmin influenced yield more than rainfall or rainy days. This may be due to the fact that the vines were irrigated during critical stages during summer in these plantations. The table 4 clearly shows that Tmax had negative influence on yield in all the plantations. One degree increase in temperature can result in 1.89 to 20.86 units (kg) reduction in yield in different plantations. T min and rainfall show positive influence on yield in 5 out of 6 plantations and rainy days showed positive influence in 4 plantations. One degree increase in minimum temperature can result in 4 units reduction in yield to 20.12 units increase in yield in different plantations. Similarly, one mm of rainfall can result in 0.05 units increase to 0.04 units decrease in yield in different plantations.

Normalized yield deviations

Normalised yield deviations (NYD) were worked out (deviations from the mean for two decades) for different stations based on the climatic data for the past two decades. This was regressed with rainfall, Tmax and Tmin to get regression line which can predict the yield deviations if values for rainfall, Tmax and Tmin are substituted in the equation. The equation for Valparai (Coimbatore) is,

$$Y=(0.18433+(0.0000158X1)-(0.01354X2)+(0.006263X3)$$

Where Y = yield, X1 = rainfall, X2 = Tmax and X3 = Tmin

Table 4 Regression equation for different plantations in Coorg based on rainy days, rainfall, Tmax and Tmin (1995 to 2005)

Plantation	Intercept	Rainy days	Rainfall	Tmax	Tmin
1	823.78	1.2508	0.0100	–20.8613	13.7220
2	165.44	–0.5934	0.0112	–4.6378	3.4138
3	319.08	–1.0674	0.0133	–11.3859	9.4886
4	232.44	0.0443	–0.0048	–3.7249	–4.1680
5	481.11	2.5438	0.0226	–13.3369	13.8801
6	509.65	2.5222	0.0527	–1.8942	20.1237

Based on the above equation, NYD has been predicted using HadCM3 RCM predictions for 2020, 2050 and 2080 for the grid covering Valparai and Wynad for A2a scenario is given below in Table 5. The actual station values for the year 1980 were used as base values.

Table 5 indicates that for Valparai (Coimbatore), rainfall, Tmax and Tmin all showed increasing trend with future climate projections while the productivity does not seem to vary much from the present values as indicated by normalized yield deviations. On the other hand, for Wynad, future climate projections shows a slight reduction in rainfall while both Tmax and Tmin show an increasing trend and the productivity prediction also shows an upward trend of about 20% from the present values.

April-May seems to be very important for pepper from the point of new flush, flower initiation as well as yield. Hence, good soil moisture during April May has positive influence on yield. Two irrigations/month @ 50 litres/vine per irrigation during March and April months significantly enhanced pepper yields under Mercara conditions (Ankegowda *et al.* 2011). April-May rainfall had positive association with productivity in most of the pepper growing areas though the correlation was not significant in some places. Earlier studies revealed a significant correlation between rainfall received (amounts to 100 mm to attain field capacity during first half of May) with yield in black pepper (r=0.75) and also with rainfall received during the second half of June and yield (r=0.90) (if preceded by rainfall in the first half of May). Maximum (82.43%) total annual growth of fruiting branches was required in June-July coinciding with peak period of monsoon for higher productivity of the vine (Pradeepkumar *et al.* 1999). The studies on association between black pepper yield and climatic variables indicated significant effect of rainfall, Tmax and Tmin on black pepper yield and the magnitude of association was of the order RHmax>Rain>Tmin>Tmax (Kandiannan *et al.* 2011). Correlation between pepper productivity and climatic parameters at Panniyur based on climatic data for 11 years showed that maximum temperature and number of sunshine hours in the first fortnight of March had positive impact on productivity, while mean relative humidity of the July first fortnight, number of sunshine hours received during the February first fortnight and April second fortnight, and mean maximum temperature during the June second fortnight had negative influence on productivity (Pradeepkumar *et al.* 1999). The late commencement of South West monsoon causes a delay in flower initiation of black pepper. Pollination and development of berries are affected due to the failure of adequate post blossom rain. It is proposed that an ideal black pepper genotype should have dehydration tolerance and should produce a minimum of 60% yield at 50% available soil moisture (Krishnamurthy *et al.* 2011). Such a variety can produce a sustainable yield under changing climatic conditions, especially under low moisture conditions due to frequent drought conditions. Similarly, another character which may be very important under changing climatic conditions is the photosynthesis and stomatal conductance and the limits for these traits have been proposed for an ideal genotype (Krishnamurthy *et al.* 2011) and black pepper variety Panniyur-1 meets the requirements in terms of photosynthesis and stomatal conductance (Krishnamurthy and Chempakam 2009).

In Kannur, area under black pepper cultivation reduced from 35 654 ha during 1995 to 23 341 ha during 2004 and production also came down from 9 334 to 4 412 tonnes. But in Wynad, area under black pepper increased from 32613 ha to 40088 ha and the production from 10 242 to 13 080 tonnes during the corresponding period. Area reduction in Kannur may be due to the fact that farmers look for more remunerative crops such as rubber, coffee etc. due to non-sustainability of the crop because of very high cost of cultivation and low market price for the produce. The area increase in Wynad may be due to the juvenile gardens which started yielding. This shows that apart from climatic factors, price and management practices may also play a role in decreased production. However, productivity showed a marginal increase during the period in both the places. In Valparai, the area under black pepper is very less compared to other growing areas. Also, pepper is not the main crop of

Table 5 Projected yield deviations for Valparai and Wynad based on A2a scenario of HadCM3 RCM predictions

Year	Rainfall (mm)		Tmax°C		Tmin°C		NYD	
	Valparai	Wynad	Valparai	Wynad	Valparai	Wynad	Valparai	Wynad
2020	5 181	2 605	25.5	31.70	16.6	20.82	0.0252	0.1932
2050	5 182	2 600	26.4	32.63	17.5	21.74	0.0183	0.2221
2080	5 184	2 592	27.4	33.59	18.5	22.68	0.0108	0.2512

the region unlike in Idukki or Wynad. So, there was not much shift in area and the production also remained same. Rainfall and Tmax also did not show any trend supporting the results of the study.

It is believed that the global temperature will rise 1° and 3.5°C up to 2100. It is also predicted that rainfall is likely to decrease from the present levels. Global climate change if occurs will definitely affect agriculture. Anticipated changes in global rainfall and temperature patterns together with the established increase in atmospheric CO_2 will affect the production of crops throughout the world. It was seen from another experiment that most of the popular varieties of black pepper (IISR as well as Panniyur varieties) showed a slight reduction in leaf area accumulation, plant height and photosynthetic rate at two degrees above ambient temperature indicating that varietal response to temperature changes (2 – 3 degrees) though exists, but may be minimal, at least in these varieties. Moisture stress is known to reduce yields irrespective of varieties, but the extent of yield reduction may depend upon the variety. It is also reported in black pepper that berry set percentage is significantly reduced if there is reduction in leaf area of subtending leaves during berry development period (Krishnamurthy *et al.* 2000). But such a reduction in leaf area was not noticed in the present study. From the results obtained in this study, climate change in terms of increase in maximum temperature is likely to reduce yields in both plains as well as higher elevations while in higher elevations, increase in minimum temperature may compensate for reduced yields due to increase in maximum temperature, thus maintaining the yield levels. Though varietal response for temperature and soil moisture may vary, it was seen that Panniyur-1 and Karimunda are the predominant varieties grown in all the pepper growing regions and these varieties respond uniformly to the changes. Reduction in rainfall during April-May and increased rainfall during December-January may reduce the yields.

In conclusion, the trend analysis of the past climate indicated that rainfall is showing a decreasing trend while Tmax and Tmin are showing an increasing trend. Black pepper productivity also showed a decreasing trend. Tmax was negatively correlated while Tmin in general was positively correlated with productivity in high elevations. Rainfall during December-January was negatively correlated while the same was positively correlated during March-April with productivity. Future yield prediction based on HadCM3 regional climate model indicated increased yield levels for Wynad but no change from the current levels for Valparai. Apart from the weather parameters used for the study, other weather variables such as light and humidity and other factors such as cost of cultivation and price for the produce, diseases and management practices definitely have a role in production and productivity of black pepper. In this study, only major climatic factors, ie rainfall, rainy days, maximum and minimum temperatures were taken in to account. So future studies should aim at considering all the factors that are responsible for low productivity and quantification of individual component factors.

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