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Impacts of weather pattern changes and a drought index on tea productivity in three main tea growing elevations of Sri Lanka

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ABSTRACT

Tea is one of the major export crops in Sri Lanka and grown in high, mid and low elevations. Recently, the highest yields have been obtained from low elevations. This study was conducted to study the impact of changing weather patterns and the effect of a drought index (DI) incorporating evapotranspiration (PET) and precipitation on tea productivity. The period of study was 2006-2017. Six sites were selected, two representing each elevation level. The productivity data and rainfall measurements were obtained from the sites, and temperature and humidity data were collected from the Department of Meteorology and the Tea Research Institute. Regression analyses were conducted between the tea productivity and weather parameters. According to the findings previous month's total rainfall, mean temperature of the current month and the relative humidity positively impact the tea yield in low elevations. Monthly relative humidity negatively impacts the tea yields of mid elevations while the rainfall of the previous month and the mean temperature of the current month impact positively on the yield at mid elevations. There was no significant impact of relative humidity on the tea yield of high elevations, but the yield was positively impacted by rainfall and temperature. According to the statistical model relationships DI two months prior to the current month negatively effect on the tea yield of low elevations and DI four months prior to the current month negatively affected the tea yield of mid elevations. In high elevations DI of the previous month and two months prior to the current month had a negative impact on tea yield. The latter findings imply that DI within the previous 2-4 months could have a significant impact on the tea productivity in a given month, depending on the elevation.

Key words: Drought Index, Potential Evapotranspiration

INTRODUCTION

Changes in climate have impacted both natural and manmade ecosystems around the world and there has been a growing concern about the impact of climate change on agriculture and different types of crops. Tea (Camellia sinensis) is considered as one of the major beverage crops in the world and it has been grown mainly in Asia and Eastern Africa at a large scale (De Costa et al., 2007).Tea is a perennial crop (Gunathilaka et al., 2017). It is having an average economic life span of 50 to 60 years (De Costa et al., 2007).

Tea is one of the main contributors to Sri Lankan's economy in terms of foreign exchange earnings, employment, and food supply (Gunathilaka et al., 2017). Paddy, Tea, Rubber and Coconut are the major agricultural crops of Sri Lanka (Central Bank, 2017). The tea industry was first implemented by the British during the 19th century in Kandy as a substitution for coffee and that has played an important role in the economy during the pre and post-independence eras of Sri Lanka (Ganewatte and Edwards, 2000). There are two main tea planting seasons in Sri Lanka: South-West monsoon season and the North-East monsoon season (Tea Research Institute, 2015). Main difference of the three tea growing regions is the height from the sea level; the high grown region is above 1200 m from the sea level, mid grown region is in between 600 m-1200 m above sea Level and low grown region is up to 600 m form sea level (Sivapalan et al.,1986).

Tea is considered as a crop, highly affected by climate change (Justus et al., 2016). Normally it is grown as a rain fed plantation crop (Karunarathne et al.,2015). The quantity of chemicals such as Flavonoids, L-theananine, caffeine, and nonproteinic amino acids in tea are highly dependent on the prevailing climatic conditions (Boehm et al., 2016). Growth of tea is affected by the climatic parameters like rainfall, temperature, intensity and duration of light. It has been found that, tea is highly susceptible for drought and does not thrive well when the moisture content is limited (Ali et al, 2014) and the drought stress severely limits the growth, while reducing the quality and the quantity of the yield (Liu et al., 2016).

In previous studies on tea, rainfall and temperature had been considered as the two main weather parameters that effect on tea productivity (De Costa et al., 2007). However the consideration of parameters such as humidity, potential evapotranspiration (PET) and drought index (DI) on tea productivity were not significantly studied.

Therefore, this research was conducted considering the importance of tea as an export crop of Sri Lanka while assessing the impact of weather parameters including humidity and extreme events such as droughts over the past years.

METHODOLOGY

Sampling Sites and Data Used

Six sites were considered in this study. Two sites belonging to each tea growing elevation of Sri Lanka (High, Mid, Low) were selected based on the availability of long-term crop production data and meteorological data (Figures 1 and 2, Table 1). Green leaf data was obtained from fields having approximately similar age group (36-40 years) and similar ratio of seedling tea plants to vegetativly propagated plants (VP). All these sites conduct estate-level management practices according to the recommendations given by Tea Research Institute of Sri Lanka. Tea Production and Meteorological Data

Monthly green leaf data and the plucking extents of the leaves were collected from respective estates together with the monthly total rainfall. Monthly mean temperature and monthly relative humidity data were collected from the closest weather station of the Department of Meteorology of Sri Lanka or from Tea Research Institute. A period of twelve years from 2006 – 2017 was considered for the study.

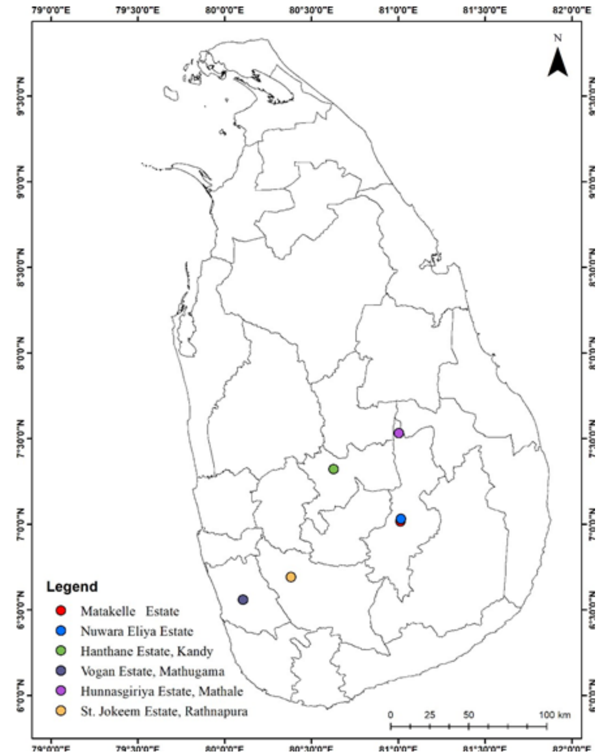

Figure 1: Map of the sampling sites. (GPS Locations collected by the author)

Figure 2: Sampling locations representing the three tea growing elevations of Sri Lanka: Mathugama and Rathnapura (low elevations); Kandy and Mathale (Mid Elevation); Nuwara Eliya and Matakelle (High Elevation)

Table 1: Predictors and their descriptions

Predictor	Description
ppt (t-1)	The total precipitation of the previous month
meantemp	The mean temperature of the current month
humid	The average relative humidity of the current month
DI(t-n)	The drought index of the previous "n" month ("n"=1, 2, 3, 4…..)

Calculations

Tea yield of each of the estate was calculated by dividing the green leaf amount by plucking extent and monthly tea yield was obtained in yield per hectare. The Potential Evapotranspiration (PET) was calculated using the Thornthwaite method (Thornthwaite, 1948; Lokupitiya et al., 2007). The monthly heat index (i) was calculated using Equation 1;

$i=(t/5)1.514$ (1)

"t" is the monthly mean temperature. Then the annual heat index (I) was calculated by the summation of the heat index values (i) of twelve months. Potential Evapotranspiration (PET) was obtained for each month using Equation 2;

$PET=1.6(10t/I)a$ (2)

Where "a" is calculated as follows:

$a=6.75 \times 10-7 \times I3-7.71 \times 10-5 \times I2+1.792 \times 10-2 \times I+4.9239 \times 10-1$ (3)

Final PET values were obtained after performing the latitudinal corrections as mentioned in the Thornthwaite method.

The PET and total monthly precipitation (P) were considered in deriving a Drought Index (DI) as stated in the Equation 4

$DI=PET/P$ (4)

Statistical Analysis

Monthly tea yield (green leaves/hectare) was analyzed against the independent weather parameters including monthly mean temperature, monthly total precipitation and monthly average relative humidity. To evaluate the impact of the drought index, log transformed monthly tea yield (green leaves/hectare) was analyzed against the DI. The yield (green leaf/hectare) was log transformed to eliminate the variation of the data points and the analyses was carried out considering DI of the previous months.

Regression analyses were performed in Minitab (version 18) software for each tea growing elevation to determine the best fitted model for the given predictor variables. The final regression models and the predictor variables and their definitions are indicated in Table 1.

Final predictor variables for statistical models were selected after checking the auto correlation (ACF) and partial autocorrelation functions (PACF). The effect of weather parameters and the DI on the tea yield was determined by the R-sq and p-values obtained for the model relationships.

RESULTS

The time series plots (Figure 3) of weather parameters and tea yield across three elevations were obtained along with the descriptive statistics in Table 2 of each parameter.

Table 2: Descriptive statistics of the studied parameters of the tea growing elevations

Elevation	Parameter	Mean	Median
Low	Annual Rainfall(mm)	3320.85	3000.55
	Temperature (C)	27.83	27.1
	Humidity (%)	79.25	78.75
	Yearly PET(mm)	343.85	21.93
	DI	0.25	0.102
	Yield(yield/ hectare)	159.74	160.95
Mid	Annual Rainfall(mm)	1930.05	1640.1
	Temperature (C)	24.89	23.9
	Humidity (%)	80.29	88.75
	Yearly PET(mm)	235.38	187.67
	DI	0.68	0.131
	Yield(yield/ hectare)	97.06	95.37
High	Annual Rainfall(mm)	2210.95	1930.4
	Temperature (C)	17.66	16.77
	Humidity (%)	83.26	84.85
	Yearly PET(mm)	55.37	53.64
	DI	0.061	0.03
	Yield(yield/ hectare)	43.96	41.62

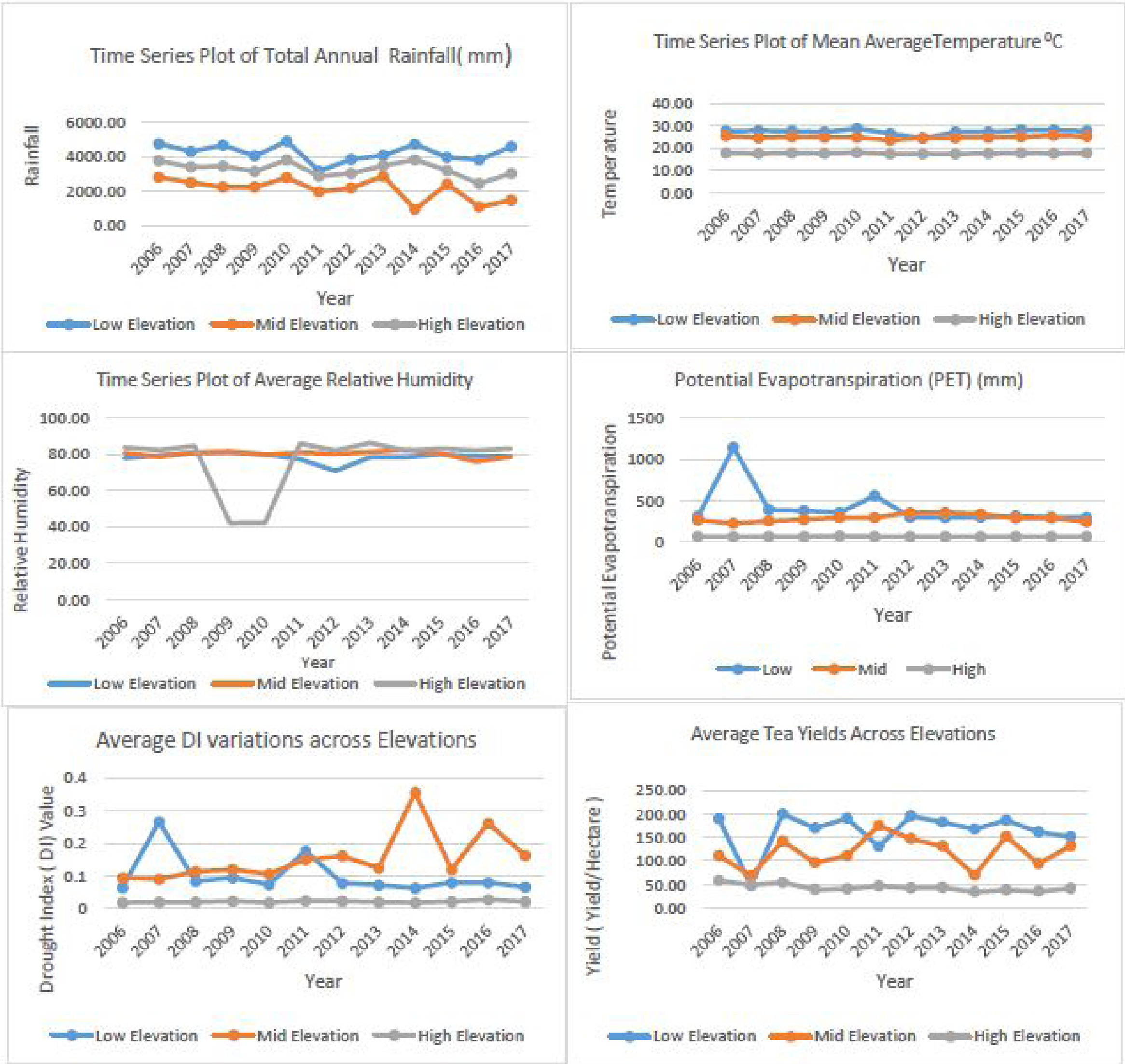

Figure 3: Time Series plots of weather parameters and tea yield across main tea growing elevations.

Model Relationships with Independent Weather parameters Low Elevation

The initial regression model (R2 adj=18.77%) for the relationship between monthly tea yield and predictor variables considering the humidity, mean temperature of the current month and the rainfall of the previous month (Table 1) was as follows.

Yield=-1398+8.77 humid+0.1354 ppt (t-1)+33.7 meantemp (5)

Values obtained for Variance Inflation Factor (VIF<5) (Table 3) revealed the absence of correlation in between the predictor variables. Lower P value (P<0.05) (Table 4) of the predictor variables indicate there was a significant contribution from the predictor variables to the yield. Equation was tested for autocorrelation and partial autocorrelation and the plots of the residuals of the above equation of low elevations reveal that there was an autocorrelation (Figure 4).

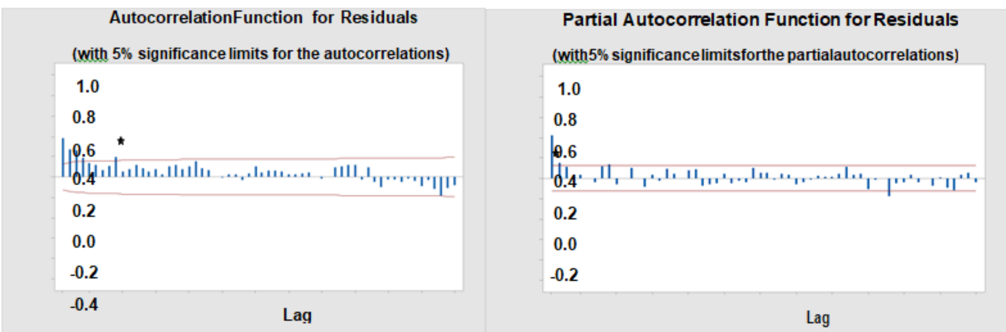

Figure 4: Autocorrelation function and Partial autocorrelation function before selecting the final predictor variables for the low elevation. High autocorrelation and partial autocorrelation are marked with

Table 3: Coefficients of the final predictor variables of the regression models with independent weather parameters of the tea growing elevations

Tea Growing Elevation	Equation	Predictor Variable	Coef	SE Coef	t-Value	p-Value	VIF
Low	Yield=-1398+8.77 humid+0.1354 ppt (t-1)+33.7 mean temp	Constant	-1398	334	-4.19	0	
		humid	8.77	1.5	5.85	0	1.02
		ppt(t-1)	0.13	0.03	3.71	0	1
		mean temp	33.7	10.9	3.1	0.002	1.01
	Yield=-1029+4.86 humid+0.0685 ppt (t-1)+26.95 mean temp + 0.5287 yield (t-1)	Constant	-1029	270	-3.81	0	0
		humid	4.86	1.27	3.81	0	0
		ppt (t-1)	0.06	0.03	2.27	0.024	0.024
		mean temp	26.95	8.75	3.08	0.002	0.002
		yield (t-1)	0.52	0.05	10.41	0	0
			-586	138	-4.25	0	
Mid	Yield=-586+0.0998 ppt (t-1)+36.80 mean temp-3.10 Humid+0.3601 yield (t-1)	Constant					
		yield (t-1)	0.52	0.05	10.41	0	0
		ppt (t-1)	0.099	0.04	-2.27	0.025	1.17
		mean temp	36.8	4.29	8.57	0	2
		humid	-3.1	1.05	2.97	0.004	1.07
		yield (t-1)	0.3601	0.05	7.06	0	1.99
High	Yield=-695.6+0.1403 ppt (t-1)+51.93 mean temp+0.3770 yield(t-1)	Constant	-695.6	89.1	-7.81	0	
		ppt (t-1)	0.1403	0.05	2.52	0.013	1.04
		mean temp	51.93	5.57	9.33	0	2.13
		yield (t-1)	0.377	0.05	7.02	0	2.08

Table 4: Summary of impact of independent weather parameters on tea productivity in the three tea growing elevations.

Tea growing Elevations	Variables and their influence on productivity (positive/negative)	R-sq adjusted value
Low	Previous month's precipitation(Positive) Monthly mean temperature(Positive) Humidity of the current month (Positive)	45.71%
Mid	Previous month's precipitation(Positive) Monthly mean temperature(Positive) Humidity of the current month (Negative)	74.06%
High	Previous month's precipitation(Positive) Monthly mean temperature(Positive)	69.34

A new predictor variable (previous month yield (t-1)) was introduced to the equation to eliminate the autocorrelation. Equation of the obtained new regression model (45.71%) given in Equation 2.

Yield=-1029+4.86 humid+0.0685 ppt (t-1)+26.95 mean temp+0.5287 yield (t-1) (6)

Obtained Durbin–Watson Statistic (d) for the Equation 2=2.28966

The autocorrelation function (ACF) and the partial auto correlation function (PACF) plots of the residuals of the regression model two reveal that there is no autocorrelation after introducing the new predictor variable (Figure 5). This was also confirmed by the Durbin – Watson Statistics (d) as the obtained d value is greater than that of the upper level (d>dU, dU=1.99075).

The above regression model equation for low elevations states that rainfall of the previous month; mean temperature and the humidity of the current month have a positive impact on monthly tea yield.

Table 5: Coefficients of the predictor variables of the final regression models with Drought Index (DI) of the tea growing elevations

Tea Growing Elevation	Final Regression model quation	Predict or Variable	Coef	SE Coef	t-Value	p-Value	VIF
Low	Log Yield=0.3692-0.0378 DI (t2)+0.7699 Log Yield (t-1)	Constant	0.3692	0.091	3.21	0	
		DI (t-2)	-0.0378	0.021	2.98	0	1
		Log yield (t-1)	0.7699	0.0437	21.16	0.001	1.01
Mid	Log Yield=0.3692-0.0378 DI(t2)+0.7699 Log Yield (t-1)	Constant	0.3949	0.0791	4.99	0	
		DI (t-4)	-12.55	4.1	-3.06	0.002	1
		Log Yield(t-1)	0.8411	0.0365	23.07	0	1
High	Log yield=1.230-52.6DI (t-1)30.1DI (t-2)+0.3412 Log yield (t-1)	Constant	1.23	0.163	8.01	0	
		DI (t-1)	52.6	14.3	3.74	0	1.9
		DI (t-2)	30.1	12.1	1.52	0.001	1.88
		Log yield(t-1)	0.3412	0.061	6.1	0	1.45

Model Relationships with Drought Indexes

The final regression models obtained for the low, mid and high elevation after removing multicollinearity, autocorrelation (ACF) and partial autocorrelation (PACF) following the same steps as for the low elevations is given in the Table 5

DISCUSSION

Several previous research studies are available on the impact of weather parameters, commonly temperature and rainfall, on tea productivity. However, consideration of relative humidity is lacking in previous research studies. To our knowledge there were not any studies conducted analyzing the impact of the ratio between potential evapotranspiration and precipitation as a DI on the tea yield in main tea growing elevations in Sri Lanka. Therefore, this research is the first of its kind which considered relative humidity, temperature, precipitation, and the DI on tea productivity.

Tea leaf production was found to be increased due to the increased rainfall shown by Ahamed et al. (2015). This could be the reason to obtain a positive impact of rainfall on tea yield in the final regression models across the elevations. In field experiments carried out by Ali et al. (2014) with weather data showed that increase highest tea leaf production per hectare lies on 4000 mm to 4600 mm rainfall. Therefore this may have been the cause to obtained higher tea yields in low elevation as the elevation has the highest reported rainfall (4000 mm-4500 mm) comparatively to other elevations.

According to Stephens and Carr (1990), the extension rate of tea shoots is usually temperature dependent and increases with increasing temperatures. So this could be the possible reason to obtain a positive impact of temperature on tea yield across all three elevations. Temperature below 13°C possibly damage the foliage stated by Carr (1972).This could have been a possible reason to obtained lowest yield from higher elevations as the elevation has the lowest temperature.

The reduction in relative humidity, will adversely affect tea production stated by Han et al (2017) and tea benefits from high atmospheric humidity stated by Eden (1965).This could be the possible reason to obtain a positive impact of relative humidity in low and mid elevations. According to Bhagut, Barudah and Safique (2010), continued hot-humid conditions during the growing season are required for successful cultivation and growth of tea, and according to the Tea Research Institute of Sri Lanka, (2008), the ideal temperature for tea growth is considered to be 18-25°C. In this study we did not obtained any impact of humidity on high elevation tea yield. This could have been because the elevation does not maintain sufficient temperature level even though it has the reported highest relative humidity. According to Tea Research Institute (2008) high elevation tea productivity equally impact from high wind and mist. This could be the reason to obtained yields within the usual range without a significant drop in years 2009 and 2010 in which high elevations had the lowest humidity.

Many past studies had considered DI incorporating the ratio between potential evapotranspiration and precipitation to study the impact of droughts eg: Poznikova et al. (2013). In a study carried out in China, Ahmed et al. (2014) found that 50% reduction in tea growth in Yunnan province during the spring drought compared to the monsoon period. Carr (1977) also revealed that tea tends to develop water stress due to the gradual development of the drought. This could be the possible reason to obtain a negative impact of DI on tea yield across all three elevations. In 2007 the low elevations and in 2014 the mid elevation experienced it lowest yields and both of these years reported the highest values in DI along with high PET. Comparatively low rainfall was observed in mid elevation in 2014.

One of the biggest challenges in carrying out this study was the difficulty in obtaining productivity data and meteorological data for a twelve-year period due to the lack of well documented data. Also it was a challenge to select estates having plants with similar age groups, soil types and estate management practices. This limited the possibility of selecting more than two estates per tea growing elevation (Table 6).

Table 6: Summary of impact of DI (Drought Index) on tea productivity in the three tea growing elevations.

Tea growing Elevations	**Drought Index (DI) (positive/ negative)**	**R-sq adjusted value (%)**
Low	DI (t-2)(negative)	58.81%
Mid	DI (t-4)(negative)	71.74%
High	DI (t-1)(negative) DI (t-2)(negative)	57.28%

We recommend having further validation of the specific model relationships obtained through the current study once more data are available. The elevation-specific model relationships between tea productivity and weather parameters can be used in predicting the future yields within the relevant plantations. The findings of this study can contribute to the tea plantation sector in Sri Lanka. It is important to consider the findings of this study in order to develop better drought tolerant breeds and also to go for better estate management practices to cope up drought conditions and changing weather patterns in the country. This research study directly provides important findings to those who involve in this sector including tea researchers, superintendents and also the tea estate labourers.

CONCLUSION

According to the outcome of the study statistical model relationships revealed that previous month's total rainfall, mean temperature of the current month and the relative humidity positively impact the tea yield in low elevations and monthly relative humidity negatively impact the tea yields of mid elevations. Rainfall of the previous month and the mean temperature of the current month impact positively on the yield from mid elevations. There was no significant impact of relative humidity on tea yield of upper elevations, but high elevation tea yield was also positively impacted by rainfall and temperature. Considering the outcome of the all three elevations with independent whether parameters, it can be concluded that tea productivity vary depending on the tea growing elevation's climate variation.

Statistical model relationships also revealed that the DI two month prior to the current month negatively effect on the tea yield of low elevations and DI four months prior to the current month negatively affect the tea yield of mid elevations. In high elevations DI of the previous month and two months prior to the current month negatively impact on tea yield. Considering the outcome of the all three elevations, it can be concluded that tea growth is highly susceptible to droughts and the DI within the previous 2-4 months could have a significant impact on the tea productivity in a given month, depending on the elevation.

Therefore these findings can be effectively used in developing drought tolerant tea breeds and also to develop estate management practices. According to the available literature this is the first kind of study which considered relative humidity as an independent weather parameter and impacts of drought index on tea productivity. Findings of this research can be considered in the decision making processes on agriculture exports of the country while considering the impact of labour forces and other socio economic impacts associated with the tea industry.

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