Estimating economic impact of weather variations on perennial crops : the case of tea production in Sri Lanka
(working paper)

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Abstract

Changing weather patterns are increasingly affecting production in the agriculture sector. Impacts on perennial crops are likely to be considerable as these crops are less adaptable hence more vulnerable to variation in weather. We evaluate the effect of weather variations on tea yield using a unique monthly panel dataset from a representative cross section of 40 estates in Sri Lanka's tea plantation sector, over a 15 year period. This study uses a translog production function to quantify how changes in weather influence tea yield alongside other variable inputs. Results show standard responses to variable labour and fertiliser as inputs and indicate that on average tea yield increases with increasing temperature and with increasing precipitation.

Key words: climate change, adaptation, panel data, translog, elasticity
JEL classifications: Q12, Q54

1. Introduction

Many studies have reported that modified weather patterns associated with global climate change are negatively affecting the agriculture sector in developing countries (Feng et al., 2010; Guiteras, 2009; Schlenker & Lobell, 2010; Welch et al., 2010). Perennial crops such as tea, rubber, coconut and oil palm which have played a significant role in developing nations' economies over many decades are likely to be less adaptable to changes in weather and climate. Many studies in the literature have focused on climate change impacts on important annual crops such as wheat, corn, maize and soy bean. However, to date, comprehensive assessments of the economic impacts of weather variations on perennial crops are very rare in the literature[1]. This study will address this information gap by analysing yields from the tea plantation sector in Sri Lanka - as an example of a plantation crop in the economy of a developing country.

The plantation crop sector (tea, rubber and coconut) is very much a key player in the Sri Lankan economy in terms of foreign exchange earnings, employment generation, food supply and delivery of a number of important environmental benefits (Herath & Weersink, 2009; Illukpitiya et al., 2004). Amongst those, tea (*Camellia sinensis* L.) has become Sri Lanka's foremost plantation agricultural export and primary source of foreign exchange (Central Bank of Sri Lanka, 2013; Ganewatta et al., 2005; Wijeratne, 1996). In 2014, Sri Lanka produced about 338 million kg of tea, about 9% of world tea production, and accounted for 18.3% of tea exports globally (Central Bank of Sri Lanka, 2014). Sri Lanka is the world's second largest tea exporter and around 220,000 hectares are covered in green tea bushes which help to mitigate greenhouse gas emissions. The tea sector contributed 15% to total foreign exchange earnings in 2013 and hence plays a key role in the Sri Lankan economy (Central Bank of Sri Lanka, 2013; Ganewatta et al., 2005). The plantation sector is the largest employer in Sri Lanka and in particular the tea sector provides employment opportunities for 10% of the total work force (FAO, 2014; Ganewatta et al., 2005; Wijeratne, 1996). More than 90% of the tea produced in Sri Lanka goes to the export market (Central Bank of Sri Lanka, 2013; Ganewatta et al., 2005; Hettiarachchi & Banneheka, 2013).

However, changes in temperature, precipitation and the occurrence of extreme weather events such as droughts and high intensity precipitation have affected the sector, particularly as most production is rain-fed. Yield and production of tea are greatly influenced by weather conditions (Costa et al., 2007; Wijeratne et al., 2007). Therefore tea production responds strongly to changes in weather patterns. Total tea production and average tea yield in Sri Lanka are shown in Figure 1 for the period 1964 to 2012. Total tea production and average yield showed marked declines in 1983, 1992 and 2009 due to severe droughts (Central Bank of Sri Lanka, 1992, 2009; De Costa, 2010; Wijeratne, 1996). A production decline of four percent over the previous year was recorded in 1983 due to first quarter drought. The lowest total production of tea over the past fifty years was recorded in 1992, with a production decline of around 26% compared to that of 1991. A similar drought event impacted negatively on both average yield and total tea production in 2009, with total tea production in 2009 decreasing by 9.1% compared to that of 2008. Drought events in this region are primarily due to a weak South-West monsoon in the Indian sub-continent leading to a failure of wet season precipitation (Central Bank of Sri Lanka, 1992, 2009; De Costa, 2010;

[1] Dechenes and Kolstad (2011) quantify the impact of weather and weather expectations for selected perennial crops (fruit crops) in Californian agriculture. Ashenfelter and Storchmann (2010) use hedonic approach to see the effects of solar radiation and weather on revenues from viticulture.

Wijeratne, 1996). Abnormally dry 'wet' seasons have become increasingly frequent in Sri Lanka's tea producing agro-ecological zones over the past 50 years (FAO, 2014) (Figure 2).

The Sri Lanka Country Report on Climate Change predicts a 10% extension of the dry and wet seasons in the main tea plantation areas, together with increased frequency and severity of extreme weather events. The intensity of these climate impacts on tea production would likely vary across the major tea growing regions; low, up and mid country[2] (Wijeratne, 1996; Wijeratne et al., 2007). Prior research has also identified eight agro-ecological tea growing areas which are most vulnerable to climate change (Wijeratne & Chandrapala, 2014).

The negative effects of drought on tea are well documented (Upadhyaya & Panda, 2004; Wijeratne, 1996). Drought can affect both the quantity and quality (and hence value) of tea harvests, leading to considerable loss of export earnings. Additional welfare losses arise from reduced employment opportunities on tea plantations (Wijeratne, 1996). Production costs can also increase during drought due to the need for additional inputs. For example, extreme weather events cause adverse effects such as pest and disease outbreaks, loss of soil quality and rapid degradation of mulching material, leaving a poor soil for growth (Wijeratne, 1996). The additional inputs to overcome these losses will increase the cost of production.

For successful adaptation to climate change, policies and recommendations should be based on a robust analysis of the economic consequences of weather variations for tea production. This is vital for efficient and effective channeling of available resources by affected parties and for continuing sustainability of the sector itself. A robust, evidence-based model to quantify and forecast the economic impacts of weather variations would assist tea producers to identify strategies for maintaining competitiveness and enhancing the sustainability of perennial cropping in the face of climate change.

For the purpose of this paper, we initially explore how the tea yield in Sri Lanka may be affected by climate variability alongside other standard agricultural inputs using a translog production function (Christensen et al., 1973). Subsequent work will continue this investigation through the profit function (Diewert, 1971). The paper is structured as follows: a summary of the different approaches employed in estimating weather and climate effects on agricultural outputs across different countries is provided in the next section. The methodological framework Study sites and the unique dataset we used in this study are described in the section 3, with summary statistics. Regression analysis is followed by an interpretation of results in the section 4. The effects of weather changes on profitability of tea production are briefly discussed in the section 5, and conclusion is presented in the section 6.

2. Background

A number of different modelling approaches have been developed in the environmental and agricultural economics literature to link crop yield to different drivers alongside climate variables. Notably, apart from a study on impact of climate change on annual and perennial crops by Deschenes and Kolstad (2011) and use of hedonic models to study the effects of

[2] Low-country is the term used for tea plantations located between sea level and elevations of 300 m , mid-country plantations are located between 300 - 600 m above mean sea level, and up-country tea is grown in plantations at elevations above 600 m.

solar radiation and weather on viticulture by Ashenfelter and Storchmann (2010), all previous studies on estimating the effect of environmental factors on agricultural outputs were applied to short-term crops such as corn, maize, wheat, soy bean and grains. This study therefore contributes to the sparse literature on the potential impacts of climate on longer-term plantation crops, which are known to be extremely important in the agricultural sector of many developing countries.

Early empirical studies used multiple regression analysis to estimate the effects of weather and climate on corn yield in the United States. Thompson (1969), Huda et al. (1976) and Chang (1981) are prominent examples but with an inherent limitation that yield is assumed to respond linearly to climate and weather. Katz (1977) points to the simplicity and statistical limitations such as non-linearity and correlated predictor variables which are intrinsic to these models. These studies have received little attention in the agricultural economics literature, presumably because of their significant limitations.

Production function approaches have frequently been used to estimate the impact of climate on crop yield in combination with climate change predictions from climate simulation models. For example, Adams (1989), Adams et al. (1990), Liverman and O'Brien (1991) and Rosenzweig and Parry (1994) examine the effect of climate change on agricultural outputs in a physiological context. These models assume that *farmers do not adapt crop production methods and/or adapt their land allocations as the climate changes*, which, again, are notable limitations.

The work by Kaiser et al. (1993) models grain yield in a changing climate and includes some adaptive crop management strategies such as choice of cultivars and adjusted planting and harvesting time. Results suggest that grain farmers have some adaptability in the face of a changing climate. Hansen (1991) uses a Tobit model to estimate corn yield across 10 states under both actual weather and a predicted future climate. Phenotypically-appropriate long run climate (July mean temperature and precipitation) terms and actual immediate weather terms were both included in Hansen's model to estimate observed spatial variation in corn yield. Interaction terms between immediate weather and long run climate enabled the marginal impacts of weather variation to be isolated from the longer term effects of climate. Interestingly, Hansen found that variations in weather appear to have a stronger effect on corn yield than longer term variations in climate.

A related approach is taken by Kaufmann and Snell (1997), who integrate effects of physical and social determinants on corn yield using pooled cross sectional data at county level in the United States. They develop climate variables based on the 8 stages of corn development and integrate economic and technical variables to estimate the effect of changes in physical climate. Several other studies pursue versions of the above approach (Kaylen et al., 1992; Thompson, 1986). In particular, these studies consider the effect of weather variations on yield. Lobell et al. (2007) use time series data of yield and climate pertaining to 12 different crops in Californian agriculture over a 24 year period to assess the effect of climate (monthly temperature and precipitation) on yield. Interestingly, some perennial fruit crops and nut crops are included in the analysis. Results indicate that models estimated using a small number of climate variables have the ability to explain much of the observed variation in crop yield.

Overall many of the above studies do not consider the possibility of farmers adopting adaptation measures in a changing climate, and this is a major limitation of production function approaches that often generates worst-case estimates of climate change impacts on crop yields.

A Ricardian approach introduced by Mendelsohn et al. (1994) is regarded as one of the major methodological contributions from the agricultural and environmental economics literature in estimating the effect of climate on farm revenues. This method overcomes a major limitation of the production function approach by including farmer responses to changing climate. Land values evidenced through differences in soil quality and climate is the underlying concept behind the Ricardian approach. A study by Seo et al. (2005) used a Ricardian approach to assess the impact of climate change on Sri Lankan agriculture via cross sectional data on farm revenues and production of rice, tea, rubber and coconut. The analysis makes some simplifications, in particular with respect to the unit of analysis (district) considered and the use of mean climate for predicting land values. Also because of Sri Lanka's topographical complexity, substantial variations in climate occur across small geographical areas, making regional aggregation inappropriate. Using different climate scenarios, Seo et al. predict a huge reduction (27%) in agricultural land value following from 2^{o}C temperature increase, but impacts are offset to some extent by increasing precipitation. Schlenker et al. (2005, 2006) take a similar approach, but remark that hedonic regressions cannot be used on pooled data from dry land and irrigated farms without biasing regression estimates. Schlenker et al. also find robustly negative climate effects for a hedonic approach in estimating land values for a panel dataset of dry land counties. They conclude that, because of irrigation, localized climate is not the primary determinant of production. Schlenker et al. (2007), in an interesting piece of work conducted at farm-level in California, link farmland value to both water availability and long run climate. Fine resolution (103 years) climate data are used to develop degree day variables connected to plant growth; a strong relationship is identified between farmland value and water availability.

A related approach is taken by Kelly et al. (2005) which incorporates the effects of both actual and expected weather on farm profit using a 30 year pooled time-series cross-section at farm level. They find that climate change induces higher losses, when extreme weather events are considered. However, all the above studies suffer the potential limitation, of biases in regression estimates due to confounding of climate factors with unobserved drivers of agricultural productivity.

Given these concerns, several recent works have employed panel data to investigate relationships between climate and agricultural profits or yield. Of particular note, Deschenes & Greenstone (2007) contribute an important methodology for estimating the effect of climate change on farm profits. They model annual variation of weather to estimate profits from farm production using panel data. Farm profit is expressed as a function of prices, quantities and costs for a given crop. Prices and total costs are regarded as functions of production quantities which are themselves functions of weather. Deschenes & Greenstone argue that their approach is more reliable than the hedonic approach for assessing the economic impacts of climate change on agricultural output. Using a similar approach, Deschenes and Kolstad (2011) extend this work by evaluating the effect of two climate change scenarios for Californian agriculture over the next century.

While Deschenes and Greenstone (2007) remains a vital contribution, it has been subject to critiques by Fisher et al. (2012) who show that climate change effects on U.S. agriculture are negative when the errors of Deschenes and Greenstone (2007) are corrected. Schlenker and

Lobell (2010) examine the impact of climate change on four crops in sub-Saharan Africa using a panel data model. They document the negative impact of higher temperatures on yield. Guiteras (2009) uses 40-year district level panel data incorporating year-to-year weather variation on agricultural outputs across 200 districts in India. Overall, Guiteras finds that higher temperatures reduce crop yields. Welch et al. (2010) provide the first analysis of the impact of temperature and solar radiation on rice yield in six rice producing countries in Asia. Their findings show a decline in yield at higher minimum temperatures and an increase in yield at higher maximum temperatures. Yield estimations under moderate warming scenarios show overall reductions. Lobell et al. (2011) use panel data of de-trended precipitation and temperature for all countries in the world to identify declines in maize and wheat production, but varying effects for rice and soy beans.

In summary, production function, profit function and Ricardian approaches have been used extensively in the literature to quantify the potential impact of climate change on Agriculture. But these studies all have some limitations with respect to their data and methodology. The Ricardian approach has received much attention in the literature. However, this approach is only really applicable for situations in which competitive land markets operate. Mendelsohn's approach would not be appropriate for tea production in the plantation sector in Sri Lanka, because a land market is not in operation due to two main reasons: first and foremost, whilst tea estates are managed by large private companies, the government retains ownership of the underlying land, and second, the opportunities for crop switching on tea estates are extremely limited, given long term investments in planting[3]. In essence, it might not be too catastrophic to apply production function for tea farming due to limited availabilities of adaptation options.

This study will apply production function and profit function approaches to estimate the impact of climate change on the yield and profitability, respectively, of tea production in Sri Lanka. The profit function approach recognises that plantation managers can adopt a wide range of alternative strategies to maximise their profits under changing economic and environmental conditions. Common compensatory responses include: changing types and level of inputs (e.g. fertilizer), replanting different tea cultivars and/or switching from seedling to vegetatively-propagated varieties, or establishing more shade trees.

3. Methodology

3.1. Tea yield, weather variations and climate

We use a simple approach in this paper to estimate the effects of weather and climate on tea yield using historical estate level data on Sri Lankan tea production over a fifteen year period. These estimates are then used to infer how predicted change in climate might affect on tea yield.

First, it is important to note the distinction between weather and climate. Throughout this paper, weather refers to a localized temperature and precipitation at a given time. Climate is location's weather averaged over long periods of time (i.e. 30 years).

[3] Once a tea estate is in production, tea harvesting will typically continue consistently for about 40 years thereafter.

We estimate a panel form-translog production function (Christensen et al., 1973; Ofori-Boateng & Insah, 2014; Widawsky et al., 1998) to analyse the effect of temperature and precipitation on tea yield, alongside per hectare quantities of labour and fertilizer[4,5]. The panel-data model estimated is of the form

$$lnY_{it} = \sum_{j=1}^{J} \theta_j \, lnX_{jit} + \sum_{k=1}^{K} \beta_k \, ln \quad _{kit} + \alpha_i + \mu_i$$

where, indices i and t represent estate and year-month, respectively, and j and k denote different measures of production inputs (i.e. labour, fertilizer, year time trend, months effect) and weather such as monthly mean temperature and monthly total precipitation. The dependent variable in our model is tea yield expressed in green leaf kilograms per hectare of mature tea lands. The weather variables of interest in the equation are the W for k number of different measures. The weather variables we use in the model are temperature and precipitation in an estate i and year-month t. Our model is non-linear and both month-to-month variations in historical weather and averaged weather (climate) over a period of 30 years were included. Various weather measures k were constructed ensuring the consistency with previous agronomic literature. For example, a lag period of one month for both temperature and precipitation were used in accordance with findings from previous agronomic studies[6] (Costa et al., 2007; Wijeratne et al., 2007). Number of rainfall days per month is also included in the model[7]. The estate-specific fixed effects, α_i are included in the model to control for time invariant unobserved determinants of dependent variable. Soil quality, slope and elevation are examples that an explain differences between estates. Thus, omitted variable bias will be avoided by including fixed effects in the model.

X_{jit} is the vector of factor inputs (labour and fertilizer), time trend and month dummies. Since elevation is time invariant for each estate it could not be included explicitly as an explanatory variable. We therefore included year-elevation interaction variable to see if elevation influenced the yearly time trend in tea yield. Initial graphical explorations showed strong seasonal patterns of tea yield, so month variables were included in the equation to capture monthly variation in tea yields, possibly due to additional unobserved weather variations in for example solar radiation or cloud cover. Lastly, μ_i denotes the statistical error term of the model.

3.2. Estimation

Diagnostic checks indicated the presence of heteroscedasticity and serial correlation of the error variance. We account these misspecifications using "Arellano" method to obtain robust covariance matrix estimation (Arellano, 1987; Wooldridge, 2010).

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[4] A lag period of two months was used for fertilizer in accordance with advice from agronomists in Sri Lanka (Dr M A Wijeratne: personnel communication).

[5] We included agro-chemicals as an input variable in initial regressions, but it was not found to exert a significant impact on yield. This was subsequently confirmed by Sri Lankan tea agronomists.

[6] Phenological development of tea shoot usually takes 45-60 days, depending on elevation and other bio-physical factors.

[7] Tea shoot growth depends on both intensity and distribution of rainfall. Approximately 6-7 days of monthly rainfall days are required for ideal growth.

3.3. Quantification of response of crop yields to climate change

4. Study Sites and Data

The sample size and locations for empirical data collection were selected with regard to the 21 tea growing agro-ecological regions (AER) in Sri Lanka (Figure 2), identified in a study conducted by Tea Research Institute of Sri Lanka (Wijeratne & Chandrapala, 2014), together with variations in precipitation and elevation. One AER had to be excluded from the study because of access difficulties, however only one tea estate belongs to that particular region. It was important to ensure that the dataset contained sufficient variation across key aspects of climate (e.g. precipitation and temperature) to observe potential adaptation responses such as cultivar switching and crop switching. A 'space for time' approach was used here, i.e. extending data collection across regions which experience different precipitation, temperature etc. to capture estate managers' responses to changes in those climate parameters, without the need to extend data collection across an excessive time span, given the limited availability of tea estate management records.

Sample estates were selected from the 21 AERs so as to avoid possible correlation between precipitation and elevation. The study sample comprised of 40 tea estates covering 21 tea growing AERs in Sri Lanka. The sample locations are shown in Figure 3. Data detailing quantities of input factors and tea production together with given levels of fixed factors such as elevation and precipitation were obtained directly from monthly accounts of tea estates over the period 2000-2014[8]. Estate-specific precipitation was obtained from estates' own rain gauge records. Historical temperature data for nearby weather stations were obtained from the Sri Lanka Department of Meteorology.

Data were consistent across the sample, but restricted to analysis of short term production. Capital operations involved in production were excluded from the analysis, provided that these did not have an immediate effect on the monthly revenues. For each observation the following data were extracted at monthly resolution from the estates' monthly accounts[9].

Output Variable

Monthly tea yield was calculated by dividing the total monthly production by area planted under mature tea for the month concerned.

[8] Whilst complete monthly records over the 15 years 2000-2014 (i.e. 180 data points per estate) were available for 28 estates, shorter data sequences were obtained from some estates for which earlier records had been damaged or destroyed.

[9] The estate record keeping seems to be well organized and all expenditure items related to field and factory operations are neatly recorded in monthly accounts. The estate offices prepare this record monthly and send these to head office of their plantation company for observation and verifications. Annual auditing process of accounts is mandatory for all estates. Therefore, these records are believed to be accurate. We collected the data by digitally photographing the estate record books and then transcribed relevant data manually.

Standardized Input Variables

Cropping area
The land area under tea production for the month concerned[10]

Labour
Monthly total labour expenditure and labour days were extracted directly. There was no difference in the wage rate between genders, and therefore the centrally negotiated wage rate for the plantation sector was used.

Fertilizer
The quantity used per month was calculated from fertilizer expenditure data documented in the estate records, knowing average prices for each major tea growing region. Average fertilizer prices were calculated using data from two estates per major tea growing region[11].

Weather variables

The primary weather variables included in our analysis are monthly mean temperature, total monthly precipitation, for the period 2000-2014. Tea estates in Sri Lanka only measure and record daily precipitation; we therefore use nearest weather stations' minimum and maximum temperature for our sample locations[12]. Data sources for the temperature variables were the Department of Meteorology, Sri Lanka and the Natural Resources Management Centre of Sri Lanka.

Summary Statistics

Table 1 reports the minimum, maximum and mean temperature values for weather stations located in tea growing areas in Sri Lanka and minimum, maximum and mean values for estate-specific precipitation across the three main tea growing regions in Sri Lanka.

Summary statistics for estates' tea yield and input use are presented in Table 2.

[10] Here, we consider only the mature tea fields under harvesting.
[11] A national price series for fertilizer was not available for the full duration of the data.

Table 1. Summary statistics on monthly weather parameters, grouped by elevation, over the period 2000-2014 using temperature and precipitation data from weather stations and 40 estates respectively

	Up country	Mid Country	Low country
Minimum temperature			
Minimum	11.3	16.9	21.5
Maximum	17.1	21.5	25.7
Mean	15	20.7	23.9
Mean temperature			
Minimum	16.9	22.7	26
Maximum	21.4	28.5	29.5
Mean	19.3	25.4	27.6
Maximum temperature			
Minimum	20	27	29.5
Maximum	27.3	34.9	34
Mean	23.6	30	31.4
Precipitation (mm)			
Minimum	0	0	0
Maximum	1233	1664	1145
Mean	213	254	273

Table 2. Summary statistics of monthly tea yield and input use across 40 estates, grouped by elevation, over the period 2000-2014

	Up country	Mid Country	Low country
Tea yield (kg green leaf/ha)			
Minimum	60	54	79
Maximum	1908	1050	771
Mean	512	480	410
Median	486	470	404
Area under mature tea (ha)			
Minimum	60	133	28
Maximum	546	705	258
Mean	324	339	127
Median	333	296	130
Labour (man days/ha)			
Minimum	6	5	11
Maximum	97	65	72
Mean	37	33	31
Median	37	33	30
Fertilizer (kg/ha)			
Minimum	0	0	0
Maximum	597	500	394
Mean	83	78	73
Median	69	73	64

5. Results

The estimates of the fixed effect model of translog production function are given in Table 3.

Table 3. Translog specification of tea yield under observed weather

Variable	Coefficient	Standard Error (Robust)
ln Labour (days/ha)	-2.635	(1.306)
ln Fertilizer (kg/ha)	0.307	(0.180)
ln Precipitation (mm)	0.504	(0.093)
ln Mean temperature (^{0}C)	-0.458	(2.861)
ln Labour squared	0.276	(0.116)
ln Fertilizer squared	0.016	(0.005)
ln Precipitation squared	-0.025	(0.005)
ln Mean temperature squared	-0.682	(1.024)
ln Fertilizer* *ln* Labour	-0.020	(0.010)
ln Precipitation* *ln* Labour	-0.028	(0.008)
ln Mean temperature* *ln* Labour	0.315	(0.280)
ln Fertilizer* *ln* Precipitation	-0.010	(0.003)
ln Fertilizer* *ln* Mean temperature	-0.030	(0.031)
ln Precipitation* *ln* Mean temperature	-0.023	(0.019)
Mean time trend	0.002	(0.012)
Up elevation*mean time trend (dummy)	0.012	(0.016)
Mid elevation *mean time trend (dummy)	0.000	(0.012)
February	-0.026	(0.019)
March	0.219	(0.044)
April	0.324	(0.040)
May	0.313	(0.048)
June	0.138	(0.042)
July	0.012	(0.035)
August	-0.023	(0.026)
September	0.015	(0.027)
October	0.104	(0.025)
November	0.184	(0.025)
December	0.032	(0.020)
Number of estates	40	
Number of observations	6829	
$F_{28, 6761} = 193.78, p < 2.22\text{ e}^{-16}$		
Adjusted R^2	44%	

Notes. Table list coefficient estimates from a fixed effect model and robust standard errors are given in parenthesis. Sample includes observations of an unbalanced panel of 40 estates across all agro-ecological regions of tea growing areas in Sri Lanka.

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8. Figures

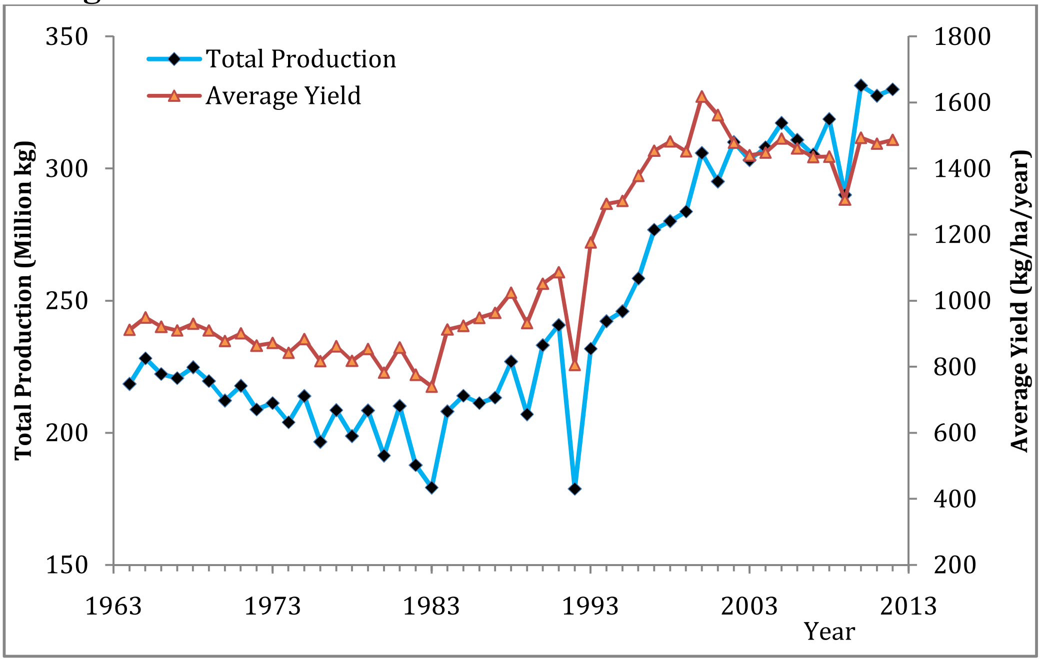

Figure 1 - Total annual tea production and average yield in Sri Lanka 1964-2012

(SOURCE: FAOSTAT)

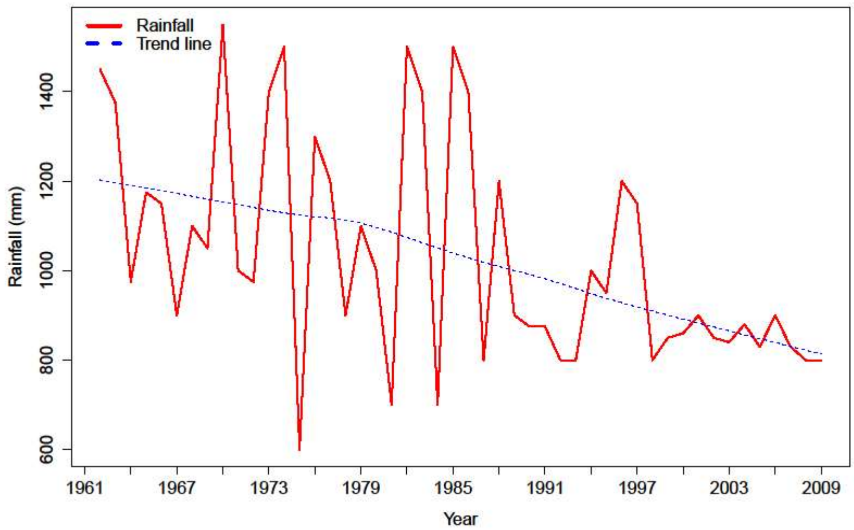

Figure 2 - Precipitation of Up country Intermediate zone 1 (IU1) of Sri Lanka during 1st inter-monsoon from 1962-2009

Source (FAO, 2014)

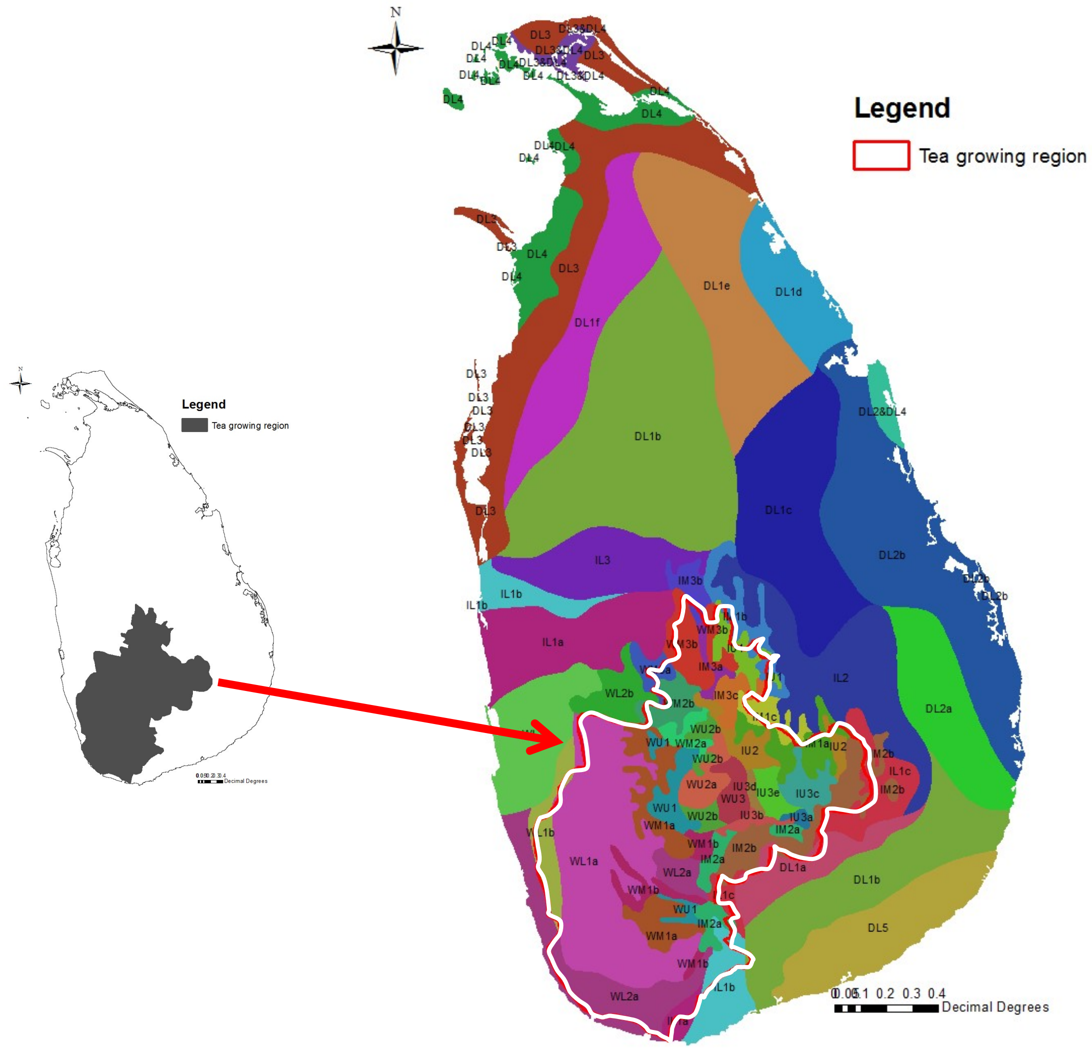

Figure 3 - Tea growing AERs of Sri Lanka (demarcated via white boarder)

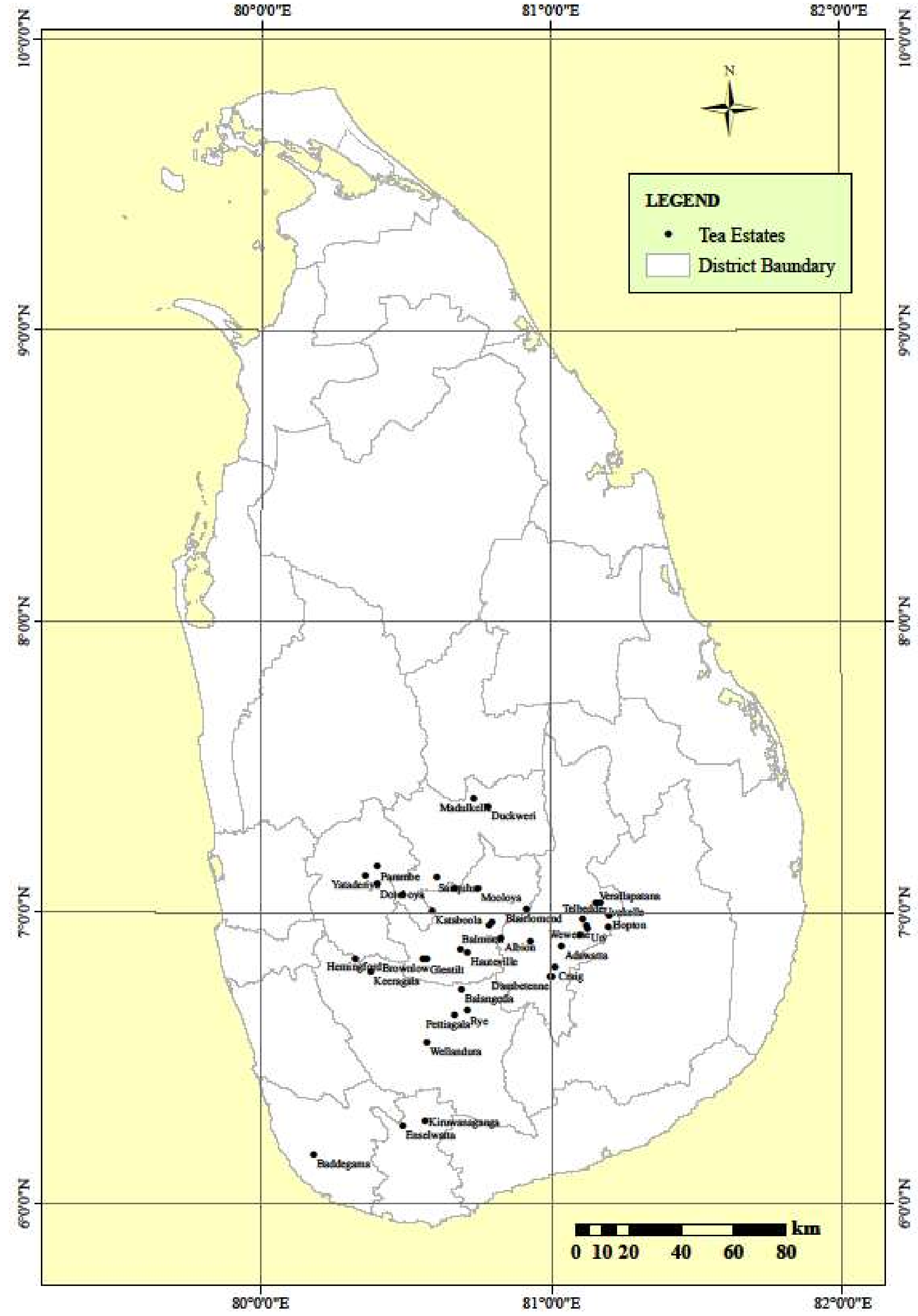

Figure 4 – Sample locations (displayed using dots). District boundaries are added in grey