SHORT REPORT

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Impact of age and management factors on tea yield and modelling the influence of leaf area index on yield variations

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ABSTRACT: The study attempted to analyse the effects of age, pruning, and fertilizer application on tea yield and to derive a relation between yield and tea leaf area index (LAI). The study was motivated by the fact that tea yield has stagnated in Northeast India. To study the effects of age, pruning, and fertilizer application on tea yield, statistical analysis was applied to the data set collected at the section level of a tea estate from 1999–2007. Tea yield is correlated with age, NPK applications, pruning, and also leaf area index. Age showed a significant negative effect ($R^2 = 0.21$–0.61). Clear negative effects of N application could be observed ($R^2 = 0.24$–0.92). A significant positive effect of pruning could also be observed ($R^2 = 0.14$–0.48). Further, an empirical equation was established between yield and measured LAI indicating that tea yield has a strong relationship with LAI ($R^2 = 0.62$). The sectional averages also show a clear negative effect of N application and a clear positive effect of LAI over tea yield. Stepwise regression confirms that LAI could play an important role in predicting tea yield.

KEYWORDS: sections, NPK applications, pruning, statistical analysis

INTRODUCTION

Tea (*Camellia sinensis*) is one of the leading cash crops in world agriculture and India is the largest producer of tea in the world after China[1]. Growth of the tea plant is dependent on many factors comprising of those that are inherent in the plant itself and those exerted on the tea crop by nature such as soil and climatic conditions, pest and diseases, and man through crop husbandry and cultural practices[2]. Management plays a vital role in tea production and its quality.

Under normal conditions, the tea plant takes its nutrients from the soil. Very small quantities of nitrogen and other elements may also be absorbed by the leaves from air and rainwater. A continuous stand of tea plants for more than 50 years exhausts the soil of its mineral supply, thus reducing plant growth and hence profitable yields. Also a possible imbalance in the relative supply of nutrients by the soil may disrupt the growth rate of the tea plant. The main nutrient elements removed from a tea plantation through harvested tea are nitrogen (N), phosphorus (P), and potassium (K) and this is attributed to the inevitable removal of the young shoots[2]. The effect of nitrogen fertilizer use on tea production is positive, but related to plant age and genotype[2]. Studies have shown that tea yield is significantly affected by age of the plants; yield decreases with increasing age[1,2]. Nitrogen fertilization is widely practised in tea plantations. It improves productivity under good management in commercial tea plantations with rates ranging from 100 kg N $ha^{-1}yr^{-1}$ in India and Kenya[3] to 1200 kg N $ha^{-1}yr^{-1}$ for green tea in Japan[4]. However, higher application of nitrogen causes higher acidification and nutrient imbalances[3,5]. Studies have also revealed that older tea plantations do not respond well to nitrogen fertilizer, so the application should be restricted to low levels (about 50 kg N $ha^{-1}yr^{-1}$) required to maintain quality[6] and to prevent damage by pests during stress periods[7]. Planting of improved genotypes and implementing appropriate N management strategies are key factors to avoid the decline of productivity associated with ageing and bush degradation[8]. N management strategies should be based on the yielding potential of tea bushes in the target environment as defined by plant genotype and age of plantations.

Pruning is seen as an important management practice in tea in the production of leaves for the manufacture of black tea[1,9]. It renews the plant, provides stimulus for vegetative growth to divert stored energy for production of growing shoots, corrects past defects in bush architecture, maintains ideal frame height for economic plucking, improves bush hygiene, and reduces the incidence of pests and diseases[10]. It also leads to enhanced branching and hence a greater number of tender leaves[11]. Plant height normally increases by 15–20 cm annually and leads to low productivity, as the plucking becomes more difficult[12]. Hence in order to maintain tea bushes in a manageable condition for plucking and enhance production by increasing branching, pruning is essential[13]. In South India, a pruning cycle of four years is practised[12]. Unpruned tea plants produce more dormant buds than growing buds[11]. Therefore pruning prior to harvest greatly improves plant productivity[14].

Most tea estate managers require information about the expected tea yield from a particular estate in advance. Traditionally, crop production forecasts were based on crop inventories (estate ledgers) and yield surveys[15]. Crop inventories were collected using census and ground survey techniques. Application of traditional techniques is expensive, time consuming, and unreliable for larger areas. Several early models developed for tea were simple statistical correlations with few variables. Leaf area index (LAI) is an important parameter in crop yield models. The LAI during the plucking stage of the tea plant is an important state variable in yield estimation models. It affects crop reflectance and is often used in crop reflectance modelling[16].

In this study, an attempt has been made to analyse the effects of plant age, pruning, and fertilizer applications on tea yield and to model the influence of leaf area index (LAI) on yield.

DATA COLLECTION

Study area

The study was carried out in the South Bank region of Assam in India. The area under investigation is Jorhat district. The city is located at 26.75° N latitude and 94.22° E longitude. It has an average elevation of 116 m (381 ft). The district spreads over 2851 km^2. Summer temperature ranges between 15–28 °C while the winter temperature ranges between 7–18 °C. The city receives an average annual rainfall of 2244 mm. There are about 135 tea estates occupying an area of 268 983 ha. The study was carried out in one estate in the district due to availability of data at the section level.

Field data

Most of the Indian tea estates range in size between 100 and 500 ha. Each estate is divided into different sections between the size of 10 and 15 ha. Sections contain tea plants of different varieties, of different age, and are managed on an individual basis. Tea yield and age data were available at the section level, for the period between 1999 and 2007. Data on fertilizer application were available at the section level.

Pruning

On pruning, tea farmers recognize medium prune (MP), medium skiff (MS), deep skiff (DS), light prune (LP), light skiff (LS), level of skiff (LOS), and unpruned (UP). Detailed pruning data at the individual section level were collected. MP removes the knots and unproductive excess woods and facilitates consolidation by infilling the vacancies. MS regulates crop distribution, reduces the effects of drought, reduces incidence of excessive dormant shoots formation, and increases the height of plucking. DS regulates crop distribution, reduces the effects of drought, reduces excessive creep, and increases the height of plucking. LP renews the wood, regulates crop distribution, reduces pests and diseases, and maintains ideal frame height of the bushes. LOS levels the plucking surface at 4–6 cm above the tipping mark. LS given at 1 cm above the previous tipping height maintains the plucking table.

Leaf area index analysis

Leaf area index (LAI) is the leaf area divided by the sample surface area[15]. It was measured using a Licor plant canopy analyser. The sections were divided into 5 m^2-quadrats and 20 random sampling points per plot were used.

STATISTICAL ANALYSIS

The variation in yield was related to management variables that could partly account for the observed variation using a least squares analysis. Annual data were considered throughout.

Age

A sectionwise linear regression analysis was carried out on estate SB to investigate the effect of age on yield. The analysis was carried out on each estate separately with sectionwise yield as the response variable and age as the explanatory variable. This model is written as

$$Y_{\mathrm{e}}(s,t) = \beta_0 + \beta_1 \mathrm{Age}(s,t) + \varepsilon(s,t), \qquad (1)$$

where $\mathrm{Age}(s,t)$ is the age of the plantations in section s in year t, while $\varepsilon(s,t)$ is the error, assumed to be independent. The subscript e denotes estate.

Fertilizers

A section level regression analysis was carried out on section-wise yields with N, P, and K fertilizer application as explanatory variables, applying the following model:

$$Y_{\mathrm{e}}(s,t) = \beta_0 + \beta_1 N(s,t) + \beta_2 P(s,t) + \beta_3 K(s,t) + \varepsilon(s,t), \quad (2)$$

where $N(s,t)$, $P(s,t)$, and $K(s,t)$ are the amounts of N, P, and K applied to section s in year t. $\varepsilon(s,t)$ are independent and identically distributed random variables.

Pruning

A section level regression analysis was carried out to investigate the effect of pruning on tea yield at the section level:

$$Y_{\mathrm{e}}(s,t) = \beta_0 + \eta_k \mathrm{Prune}_k(s,t) + \varepsilon(s,t), \quad (3)$$

where $\mathrm{Prune}_k(s,t)$ is the kth pruning type applied at section s and year t, with pruning types applied in the year before the yield. Also assigned is the effect of an arbitrary pruning ($\eta = 1$) with no pruning ($\eta = 0$) at the section level.

Leaf area index

A section level regression analysis was carried out on section-wise yields with LAI as the explanatory variable:

$$Y_{\mathrm{e}}(s,t) = \beta_0 + \beta_1 \mathrm{LAI}(s,t) + \varepsilon(s,t), \quad (4)$$

where $\mathrm{LAI}(s,t)$ is the average leaf area index of the section s in year t, and the error term $\varepsilon(s,t)$ is independent.

Fertilizers and LAI sectional average

Taking the sectional averages of NPK application and LAI, regression analysis (2) and (4) was carried out on section-wise yields while a sectionwise regression analysis was carried out with N application as the explanatory variable:

$$Y_{\mathrm{e}}(s,t) = \beta_0 + \beta_1 N(s,t) + \beta_2 \mathrm{LAI}(s,t) + \varepsilon(s,t), \quad (5)$$

where $N(s,t)$ is the yearly average amount of N applied to section s in year t, $\mathrm{LAI}(s,t)$ is the average leaf area index, and $\varepsilon(s,t)$ is the error term and is independent.

Stepwise regression analysis

Taking the sectional averages of N application, pruning, and LAI, a stepwise regression analysis was also carried out on yield with N application, prune and LAI as explanatory variables.

$$Y_{\mathrm{e}}(s,t) = \beta_0 + \beta_1 N(s,t) + \beta_2 \mathrm{LAI}(s,t) + \eta_k \mathrm{Prune}_k(s,t) + \varepsilon(s,t), \quad (6)$$

where $N(s,t)$ is the yearly average amount of N applied to section s in year t, $\mathrm{LAI}(s,t)$ is the average leaf area index of section s in year t, $\mathrm{Prune}_k(s,t)$ is the kth pruning type applied at section s and year t, and $\varepsilon(s,t)$ is the error term and is independent.

RESULTS AND DISCUSSION

Age analysis

To see the effects of age on yield, a sectionwise regression analysis (1) was carried out with plant age. The results showed significant negative and linear effects on tea yield with R^2 ranging from 0.21–0.61 (Table 1). The combined year analysis also showed a significant negative effect. This also confirms that with the increase in age of plantations, the yield decreases.

NPK fertilizers analysis

The sectionwise regression analysis (2), with N, P, and K application, revealed significant negative effects of N in three sections while a significant negative effect of P and K could be observed in one section and a significant positive effect of P could be observed in another section (Table 2). The R^2 ranged between 0.24–0.92. The analysis reveals that higher application of fertilizer reduces yield but at the same time such a decline may also be governed by other factors such as cultivars used, age, and pest infestations.

Pruning analysis

Applying (3), a significant positive effect of pruning was observed for all the sections under study

Table 1 Estimated linear relationship between tea yield and age of plantations for different years ($n = 32$).

Year	R^2	Intercept	Age
2004	0.612	2021	−11***
2006	0.212	1637	−9*
2007	0.242	1861	−9*
All years	0.421	1735	−12***

For this and remaining tables:
*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Table 2 Linear relation between yield and NPK application at the section level ($n = 9$).

Section	R^2	β_0	β_1	β_2	β_3
10	0.341	1321	−3.81*	1.16**	6.73
11	0.278	937	−1.21	−0.92	7.18
25	0.235	−1028	7.41*	−4.92	−14.06
35	0.923	7937	−29.13*	−16.12**	−31.27**

Table 3 Linear relations between yield and different pruning regimes at the section level ($n = 9$).

Section	R^2	Intercept, β_0	Prune, η
10	0.285	2103	148**
11	0.141	1984	155***
25	0.373	1401	379**
35	0.480	1493	466*

(Table 3). The analysis was done considering pruning ($\eta = 1$) and non pruning ($\eta = 0$) and to see the effects for different pruning regimes on tea yield. The R^2 is low throughout. The analysis showed that yield increases if proper pruning cycle is followed as it results in younger shoot development.

LAI analysis

Sectionwise regression analysis (4) between yield and LAI showed significant positive effects of LAI over tea yield (Table 4). The R^2 ranges from 0.12–0.87. The results further showed that LAI could predict tea yield at the section level. A linear relation between LAI and average annual yield of the estate yielded a correlation coefficient of 0.62 (Fig. 1). This indicates that there is a strong relationship between measured LAI and tea yield.

Fertilizers and LAI analysis taking the sectional averages

Taking the sectional averages, linear regression analyses were carried out using (2), (4), and (5). Results obtained showed that N application had a significant negative effect on tea yield while LAI had a significant positive effect (Table 5). The results confirm that increased application of N reduces yield. The R^2 values for the different models are 0.67 for NPK, 0.51 for N, and 0.46 for LAI.

Table 4 Linear relations between yield and LAI at the section level ($n = 9$).

Section	R^2	Intercept, β_0	LAI, β_1
10	0.605	1217	169**
11	0.117	1379	124
25	0.872	525	316***
35	0.470	1510	697*

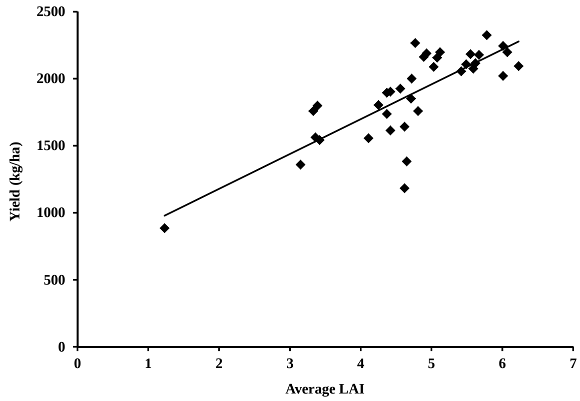

Fig. 1 LAI-Yield relationship ($R^2 = 0.62$). Regression line: $y = 260x + 258.04$.

Table 5 Linear relations between yield, NPK application, and LAI at the section level using sectional averages ($n = 9$).

Section	R^2	Intercept	N	P	K	LAI
NPK	0.667	4635	−19.84	2.06	−5.76	
N	0.514	4552	−21.46*			
LAI	0.463	291				338*

Studies have also shown that N application decreases in seedling tea with increase in age[2]. Under such situations, replanting is vital if tea productivity in ageing tea plantations is to be improved. The effects of N fertilizer were among the clearest, and to a lesser extent P and K. Clonal tea responds better to N fertilizer irrespective of age while old seedling tea does not[2]. It was stated that N management should be on the basis of yield ability of tea bushes as defined by genotype-density combinations and age classes[2]. The response of tea bushes to N increases until the age of 30 years followed by a decline[6]. Higher rates of 200 kg N $ha^{-1}yr^{-1}$ can be applied to 30 years old plantations. Younger plantations should be applied with 150 kg N $ha^{-1}yr^{-1}$. This would help in maintaining the tea quality, prevent against pests damage and also provides insights for management decisions.

Stepwise regression analysis

The stepwise regression (6) analysis shows that LAI has significant positive effect on tea yield (Table 6). The R^2 value is higher ranging from 0.47–0.87. This shows that LAI could be used as a tea yield predictor.

Table 6 Stepwise regression between yield, NPK, and LAI ($n = 9$).

Section	R^2	Intercept	LAI
10	0.605	1217	169*
11	0.729	1782	242*
25	0.872	525	316***
35	0.470	1510	697*

CONCLUSIONS

It was concluded that tea yield is influenced by age, pruning, and fertilizer application and an empirical relationship exists between yield and leaf area index. We further conclude that with the increase in age of plantations, tea yield decreases. More information could be achieved if the analysis were carried out at the individual plant level. N application showed significant negative effect on tea yield. Increased application of nitrogenous fertilizers is likely to reduce the yield in ageing plantations. But for validation of such results more sections and estates in different regions need to be considered. Pruning has a significant positive effect on tea yield indicating yield increases when the proper pruning cycle is followed. As a strong relationship between tea yield and measured LAI exists, LAI can be used as a predictor of tea yield. Further attempts should be made to find relations using satellite derived LAI and the results compared with measured LAI. Further, to validate the results, a detailed study involving large sample data for several sections for different tea estates under different regions have to be taken into consideration. The current study gives us an idea that such effects could be analysed and monitored.

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