Estimating the Shoot Dry Matter Production of Tea [Camelia sinensis (L.) O. Kuntze] of Cultivar TRI 2025

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Abstract— Three field experiments were conducted to study growth and dry matter production of shoots of tea cultivar TRI 2025. The study site was a smallholder tea farmer's field at Hali Ela (South), 1178 m amsl. First experiment was carried out to study the changes in number of shoots in different growth stages (i.e. buds, bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves and banjies) with time. Observations were taken for one year. In the second experiment, degree-days (thermal time) accumulated for producing different tea shoots in a plucking table of cultivar TRI 2025 were estimated. In the third experiment a mathematical model to predict the production of harvestable tea shoots was developed. There was a significant difference among the mean number of total shoots in the plucking table with time (i.e. month of a year) representing different growth stages (i.e. buds, bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves). The highest number of total shoots was recorded in April 2014 (128.25±9.137) and lowest during the month of September 2013 (79.2±9.137) (P<0.05).The average leaf area (LA) (cm2) of shoots at different growth stages could be estimated as a function of cumulative thermal time (R2~1). Fresh weight of harvestable TRI 2025 tea shoots could be predicted with a high precision (R2=0.9).

Key words: Shoot Dry Matter, TRI 2025, Tea [Ca melia sinensis (L.) O. Kuntze], smallholder tea farmer's field at Hali Ela (South) (latitude is 6.956 and longitude is 81.034)

I. INTRODUCTION

Tea [Camelia sinensis (L.) O. Kuntze] is one of the most important plantation crops in Sri Lanka, which is ranked as the fourth leading tea exporting nation in the world. The tea industry remains a vital contributor to the country's exports, accounting for 2 % of the GDP while generating 11.2 % of net foreign exchange earnings for the nation [1].

The processes of dry matter production and partitioning in tea are still not well understood, making their prediction difficult since it is dependent on many factors comprising of those that are inherent to plant itself and those exerted on the tea crop by nature. There is a need for a simulation model which synthesizes existing information on the mechanisms of dry matter production and partitioning in a form which can be used for these purposes. The economically important part of tea is the tender shoots consisting of two or three leaves with an apical bud. The yield and distribution of yields throughout the year depend on three principal yield components, namely the number of shoots harvested (per m²), the mean shoot dry mass at harvest (g), and time taken for an axillary bud to grow into a shoot suitable for harvesting [2].

Number of shoots and the mean weight of a shoot at harvesting are greatly influenced by the rate of shoot growth. Tea shoot growth varies with the cultivar, season, inputs such as nitrogen (N), and stage in pruning cycle. Therefore, it is important to get knowledge about the shoot growth pattern and the distribution of shoots on the bush for plucking purposes.

Earlier efforts on predicting the shoot growth relating to thermal development (phyllochrons) has provided platform on growth and yield simulations of tea [3]. Growing degree days based on actual temperature is a simple and accurate method to predict the developmental stage of a tea shoot [4]. The duration of tea leaf development and leaf expansion rate (LA) measured based on the cumulative thermal time is a constant, and can be considered as a characteristic of a tea cultivar [5]. Therefore, thermal time can be used to predict the tea shoot growth.

The dry mass of a tea shoot depends on shoot size, fresh mass (or fresh weight) and dry matter content of a particular shoot [2]. Dry matter content of a shoot depends on dry matter partitioning. According to the reference [6] dry matter partitioning to a shoot is affected by weather condition. As the marketable product of tea is dried leaves, dry matter content of tea shoots is of great importance to tea producers. Mature foliage of a tea bush is known as the "source" of dry matter production and roots and growing buds are known to be the "sink". Photo-assimilates producing in the foliage canopy of tea have to be partitioned to newly growing shoots for yield formation and to other parts of the bush (i.e. maintenance foliage, branches, stem and root system) for further growth of the bush. In substance, the amount of assimilates partitioned to new shoots determines mean weight per shoot (W_{sh}) and thereby partly determines tea yield. Previous studies [7] found that the sink capacity of the bud, first, second and third leaf from the apical bud declined in the order 100, 70, 40, 30 percent, respectively of that of the apical bud.

This paper describes the potential production of tea cultivar TRI 2025 in the up country of Sri Lanka in relation to shoot population dynamics with routines describing dry matter production and partitioning assuming that water and nutrients are non-limiting throughout the year, and that there are no effects of pests and diseases.

The objectives of the study are; (i) to study the changes in number of shoots at different developmental stages (i.e. buds (Active and dormant), bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves) with time (i.e. month of a year)

(ii) to estimate the leaf area of a developing and harvestable tea shoot as a function of thermal time and, (iii) to predict the production of harvestable tea shoots.

II. MATERIALS AND METHODS

Observation were made at a smallholder *tea* farmer's field at Hali Ela (South) (latitude is 6.956 and longitude is 81.034) and laboratory work was conducted at Uva Wellassa University during June 2013 to June 2014. Elevation of the study location is 1178 m amsl and belongs to Agro-ecological region of IM1a. There experiments were conducted at the same time in order to achieve the objectives.

In the first experiment, the cultivar was TRI 2025 and 10 m^2 plots of plucking table with ten replicates were used. Number of shoots in different growth stages (i.e. buds (Active and dormant), bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves and banjies) were recorded at seven days interval (harvesting intervals) for one year period. At the same time banjies and pluckable shoots having active bud with three leaves were plucked. Weather data were obtained from the meteorological station at Badulla. Data analysis was done using Minitab 16 and MS-Excel softwares.

In the second experiment, daily minimum (T_{min}) and maximum (T_{max}) temperatures were obtained from the meteorological station at Badulla. Hence, Badulla and Hali Ela (South) belong to same Agroecological zone of IM1a. to calculate thermal time *(TT)* / phyllochron (°C days) in order to develop relationship between leaf area (LA) of shoots at different development stages (i.e. fish leaf, first, second, third normal leaf and bud) and thermal time (TT). In this regard leaf area had to be simulated with the thermal summation applying into regression equations developed [4]. It was assumed that a specific number of phyllochron is required for the completion of a particular stage of leaf development and after completion of a particular leaf stage shoot enters the next stage of leaf development. Data analysis was done in Minitab 16 and MS-Excel software.

The cumulated thermal time (TT) over the growing period was calculated using following equations (1,2 and 3) [8].

$$T_{mean} = \frac{(T_{\max} + T_{\min})}{2}$$

1) TS=0, If $T_{mean} < T_{base}$ or $T_{mean} > T_{ce}$
2) TS= T_{mean}-T_{base}, If $T_{base} < T_{mean} < T_{opt}$
3) TS= $[(T_{opt} - T_{base}) \times (1-(T_{mean} - T_{opt})/(T_{ce} - T_{opt})]$, If $T_{opt} < T_{mean} < T_{ce}$

TT = ∑ TS

Where,

T_{mean} = daily mean temperature (°C)
T_{min} = daily minimum temperature (°C)
T_{max} = daily maximum temperature (°C)
T_{base} = base temperature (°C)
T_{opt} = optimum temperature (°C)
T_{ce} = ceiling temperature (°C)
TS = thermal sum (°Cd)
TT = cumulative thermal time (°Cd)

It was considered that T_{base}; 12.5 °C [9], T_{opt}; 22 °C [10] and T_{ce}; 38 °C [11] for tea cultivar of TRI 2025.

As the first step in third experiment, field observations were made for TRI 2025 using 10 m^2 sample size of plucking table with ten bushes. Average weight of shoots (g/m^2) in different growth stages (i.e. buds, bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves) were taken. Numbers of shoots from different developmental stages, calculated from the first experiment, were used to calculate total fresh weight of shoots in different developmental stages on the bush separately as follows;

Total weight of shoots (i.e. buds, bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves) (g/m^2) = Average weight of a shoot (g) × number of shoots/1 m^2

Then, as the second step in the third experiment, in finding out the simulated dry matter in a developing shoot, it was assumed that the summation of dry matter produced from shoot photosynthesis and dry matter partitioned from the maintenance canopy is equal to the total dry matter accumulated in a growing shoot. In the determination of simulated photosynthesis by the growing shoot, estimated LA in the second experiment was taken as an independent variable. Daily sunshine hours were obtained from the meteorological station at Badulla and it was converted to radiation in $MJ/m^2/day$. Radiation-use efficiency and light extinction coefficient were taken as 0.34 g/MJ and 0.6, respectively for the cultivar of TRI 2025 [12].

The potential amount of daily dry matter production by the growing tea shoot was calculated according to the following equation (4).

$$DM = S \times \varepsilon\ (1-e^{-k.LAI}) \qquad (4)$$

Where,

- DM = Dry matter production from the growing tea shoot ($g\ m^{-2}\ d^{-1}$)
- S = Daily radiation ($MJ\ m^{-2}\ d^{-1}$)
- ε = Radiation-use efficiency ($g\ MJ^{-1}$)
- k = Extinction coefficient
- LAI = Leaf Area Index

The contribution from maintenance canopy on the growth of buds, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves was considered as 100%, 70%, 40% and 30% [7]. Therefore, the amount of dry matter produced by a growing shoot through its own photosynthesis was considered as 0 %, 30 %, 60 %, and 70 % of the daily dry matter accumulated in a growing shoot for a bud, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves, respectively.

Accordingly the total dry matter accumulated in a shoot having bud with three leaves was calculates as;

$$= \text{Dry matter production from shoot having bud with three leaves})/70 \times 100$$

After calculation of dry matter production, it was converted to fresh weight basis assuming that tea leaves contain 80 % of water in its constituents Initial moisture content of fresh tea leaves varies from 70–83% depending on the climatic condition, weather pattern and the type of tea cultivar [13]. Next, measured values of average fresh weight of shoots at different stages of shoot development obtained through the third experiment were regressed against the estimates derived through the model (predicted). T test was conducted to test the accuracy of the model. It was assumed that water and nutrients are not-limiting throughout the year, and that there are no effect of pest and diseases. Data analysis was done in Minitab 16 and MS-Excel software.

III. Results and Discussion

A. *Experiment 01:*

There was a significant difference among the mean number of shoots at different developmental stages with time (i.e. month of a year) ($P<0.05$) as given in Table 01. Significantly, the highest number of buds (35±2.8) was recorded in March, 2014 while the lowest values were recorded in August, November and December which was statistically par with each other. The highest number of shoots having bud with fish leaf (BF) (19±2.6) was recorded in May, 2014 when it has been significantly lowest (10.8±2.6) in September 2013. Intermittently, shoots having bud with one normal leaf(BN1) and bud with two normal leaves (BN2) were recorded the highest values, 26.5±3.5 and 23.25±3.6 correspondingly for the month of May, 2014. Significantly the highest values for number of shoots having three leaves and bud (BN3) were recorded in first six months when the lowest number of shoots having bud with three normal leaves (6±1.9) and bud with one leaf (11.5±3.4) were observed in month of October in 2013. The number of total shoots representing different growth stages in the plucking table (i.e. buds, bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves) was the highest (128.25±9.1) in April 2014 and lowest (79.2±9.1) during the month of September 2013.

Month	M.N.S having bud	M.N.S-BF	M.N.S - BN1	M.N.S - BN2	M.N.S - BN3	Total M.N.S
06	32.4^{abc}	17^{abcd}	20^{abcd}	14^{bcd}	13.4^{a}	102.4^{bc}
07	27.5^{bcd}	12.5^{bcd}	20^{abcd}	12^{cde}	13^{a}	93^{cde}
08	24.2^{d}	12.5^{bcd}	17^{bcd}	8.2^{e}	11.2^{ab}	82.5^{de}
09	26.2^{cd}	10.8^{e}	13.8^{cd}	11.8^{cde}	7.75^{bc}	79.2^{e}
10	27.2^{bcd}	11.2^{de}	11.5^{d}	12.5^{cde}	6^{d}	81.7^{de}
11	23.8^{d}	12^{cde}	17.5^{bcd}	$10d^{e}$	7.6^{bcd}	80.0^{e}
12	23.8^{d}	11^{de}	23.7^{ab}	12.6^{cde}	12^{ab}	80.6^{e}
01	33.0^{ab}	18.7^{ab}	23.7^{ab}	21.5^{ab}	13^{a}	118.5^{ab}
02	28.5^{abc}	15^{abcde}	25^{ab}	21.5^{ab}	13^{a}	112.4^{ab}
03	34.6^{a}	16.4^{abcde}	24.6^{ab}	18.4^{abcd}	14.6^{a}	123.2^{ab}
04	34.2^{ab}	18.2^{abc}	26.5^{a}	23.2^{a}	15.2^{a}	128.2^{a}
05	33.7^{ab}	19.2^{a}	20.5^{abc}	19^{abc}	15^{a}	118.5^{ab}
06	32.7^{abc}	17^{abcd}	17.2^{bcd}	14.2^{bcde}	15^{a}	106.7^{ab}

Table 1: Statistical significance of mean number of shoots/m2 at each developmental stage as affected by the month (M.N.S= Mean number of shoots)

1) Different Superscripts Along The Column Are Significantly Different.

Distribution of different developmental stages of shoots on the plucking table at seven days interval from June 2013 to June 2014 is shown in Figure 1. There are a large number of shoots at different stages of development ranging from growing axillary buds to shoots with a few leaves.

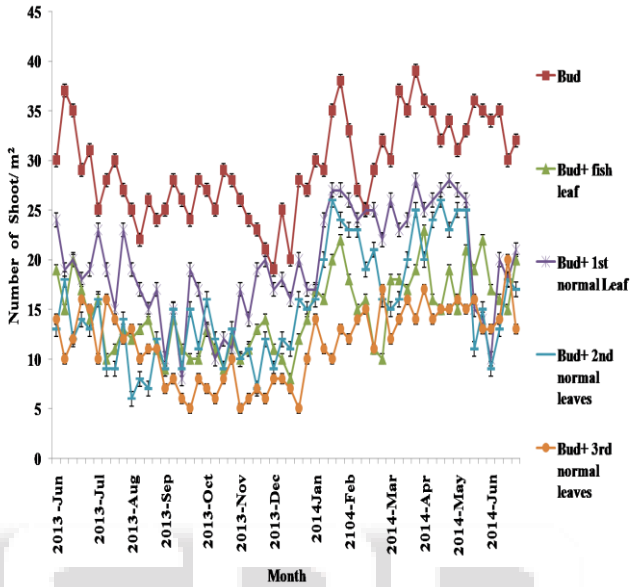

Fig. 1: Distribution of shoot generations in plucking table at seven days interval from June 2013 to June 2014. Means±stderr, n=10.

According to the Pearson's correlation coefficient (PC), there was a negative correlation between the number of shoots having bud (r=-0.362), bud with fish leaf (r=-0.318), bud with two normal leaves(r=-0.221), bud with three normal leaf (r=-0.232) and total number of shoots (r=-0.322) per unit area and the rainfall at 5% of probability level.

Climatic parameters such as solar radiation, rainfall, temperature, vapor pressure deficit and wind affect the growth of tea shoots. Temperature and rainfall have been identified as the most influential climatic factors affecting productivity of tea [14].

In early months of the year ranging from January to mid-July , there was a peak (rush) crop once all the fast growing shoots containing three leaves and bud were harvested within the peak cropping period. During the rainy periods, little or no active shoot growth, carbohydrates are mostly partitioned to roots. During subsequent warmer periods, these carbohydrates are re-translocated to the developing shoots [15]. That "peak" is known as "Fordham peak". It has been proposed that occurrence of peaks and troughs in tea yield are a result of hormonal interaction [16]. Assimilates are mostly diverted to roots during less cropping periods and are utilized by growing buds during peak periods. Therefore, a rhythemic pattern of shoot growth enables the bush to maintain a balance of shoot and root [17].

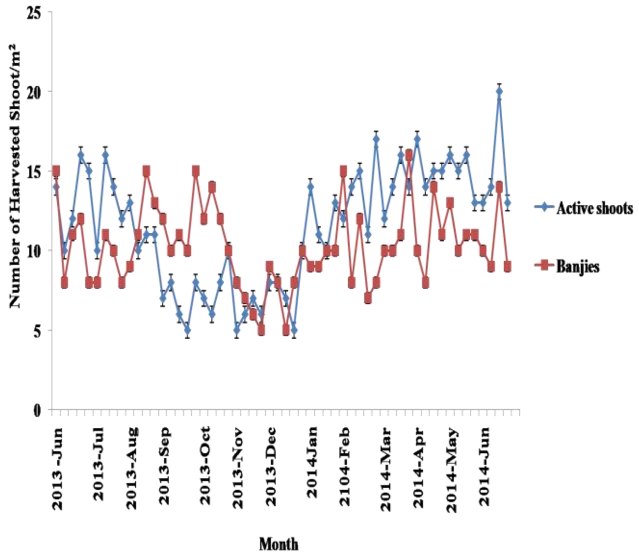

Fig. 2: Variation in the number of harvestable shoots with bud and dormant bud (banji) at the harvesting stage. Means ± std err, n=10.

The number harvestable shoots with active buds were lower during dry period of August to October 2013 while the proportion of dormant shoot was increased as shown in Figure. 2. Banji shoots refers to shoots that do not form a terminal bud but only carries fresh leaves. Field observations have shown that the number of dormant shoots are less during periods of higher leaf yield (rush crop) and high during periods of lower leaf yield. The majority of shoots produced by TRI 2025 appeared to become dormant when they are of harvestable size (Figure 2). A greater production of dormant shoots has been considered as a useful mechanism for drought tolerance [18] because it reduces the moisture requirement and the transpiration losses from the bush. Formation of dormant shoots has no significant bearing on the tea yield [19].

B. *Experiment 02:*

The average leaf area (LA) for shoots in different development stage in plucking table were estimated with reference to the regression equations developed as given in [4] .The average leaf area of shoots having bud with fish leaf and bud with one normal leaf were not significantly different with time, at 5% of probability level. Significantly, the lowest average leaf area of shoots having bud with two leaves (4.14±0.6 cm^2) and bud with three leaves (22.86±2.8 cm^2) were recorded in December, 2014.

The average leaf area (LA) (cm^2) of a shoot at different developmental stages could be estimated as a function of cumulative thermal time (Figure 3). This approach is an alternative to the leaf length (L) and width (W) based or number of days from the bud break based LA estimations. These thermal time requirements are important for managers and field staff to determine correct plucking rounds.

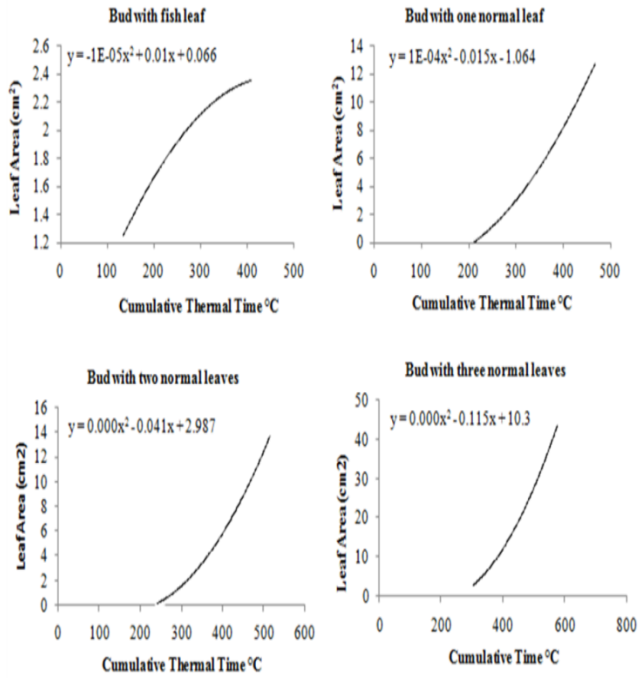

Fig. 3: Leaf area (LA) of different leaves in a tea shoots with thermal time (Jayasinghe *et al.*, 2013)

C. *Experiment 03:*

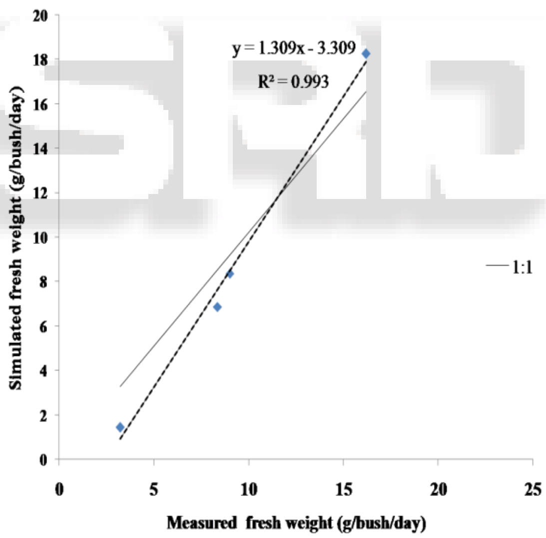

Fig. 4: Comparison of measured and simulated fresh weight for a growing tea shoots of TRI2025

Model could predict fresh weight of growing tea shoots in a tea bush very closely to that of measured (Figure 4).There was a very close relationship between the measured and simulated fresh weight of TRI2025.

According to the results generated by the two sample T-test, there was no significant difference between the mean values of simulated and measured fresh weight of a tea shoots containing three leaves with bud in a tea bush ($P<0.05$).

This simple model falls into `sink-driven' model where dry matter production is determined by the combined growth characteristics of the number of shoots or assimilate-sinks per unit area. Further work is to be done to calibrate and evaluate the model across different cultivars in different locations.

IV. CONCLUSIONS

There was a significant difference among the mean number of total shoots in the plucking table with time (i.e. month of a year) representing different growth stages (i.e. buds, bud with fish leaf, bud with one normal leaf, bud with two normal leaves, bud with three normal leaves). Significantly, the highest number of total shoots (128.25±9.137) was recorded in April 2014 and lowest (79.2±9.137) during the month of September 2013 ($P<0.05$). A simple model was developed to predict fresh weight of a tea shoots (g/bush/day) containing three leaves with bud in a tea bush for widely cultivated tea cultivar of TRI 2025.

V. ACKNOWLEDGEMENT

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