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Skiffing in Tea (*Camellia sinensis* (L.) O. Kuntze): Constructive Changes of Tea Bush by Mechanical Skiffing and Yield Prediction

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ABSTRACT

Tea skiffing brings both advantages and disadvantages to tea production. The tree canopy and plucked ratio, as well as tea quality, yield and yield components can be controlled by skiffing. Tea skiffing, on the other hand, decreases the source of photosynthesis. Advantages of this trade-off and knowledge of how to manage it is required. A better tea canopy for tea production can be achieved by shallower skiffing, which contributes to better tea quality in the first crop and greater shoot weight in the latter crop. Development of top lateral buds in skiffed branches (SBs) is predictable from the daily mean temperature and day length. Tea yield of top lateral shoots is strongly associated with meteorological factors, and thus easily predictable from multiple regression equations using days after skiffing, accumulated daily maximum temperature, daily minimum humidity and accumulated solar radiation as independent variables. For predicting total yield, prediction accuracy increases when the number of flushed shoots, which is predictable from the number of SBs, is added into independent variables. This review paper clarifies the constructive changes in tea trees by skiffing and evaluates the importance of skiffed branches in the use of tea yield prediction.

Keywords: apical bud, lateral bud, yield
Abbreviations: NSB, non-skiffed branch; **SB**, skiffed branch

CONTENTS

INTRODUCTION

Tea (*Camellia sinensis* (L.) O. Kuntze) is generally classified into two subspecies, var. *sinensis* and var. *assamica* (Sealey 1958). The former is a bush type, has small leaves, adjusts to cold regions like China, Japan and Korea etc., and cultivated mainly for green tea. The latter, on the other hand, is a tree type, has large leaves, is grown in non-frost regions such as Vietnam, India, Sri Lanka, Kenya and Malawi etc. for black tea production. Tea farmers generally conduct skiffing after plucking in every crop to trim tea bush surface uniformly so as to avoid contamination of old leaves or lignified stem from new leaves at harvesting. Tea pruning or plucking, on the other hand, differs from tea skiffing. Tea pruning is conducted to recover plant vigor and return the height of tea plants at an adequate level for optimal managements. It is usually operated in every three to four years by cutting tea trees bellow the plucking level. Tea plucking is used same as "harvesting" of new leaves.

Following the introduction of mechanical plucking in the 1970's in Japan, mechanical skiffing has expanded to Japanese tea farmers and has greatly improved not only the trimming the bush surface but also the control of flushing time (defined as more than 50% of fresh tips of leaves that emerge from winter buds), yield component and tea quality by changing skiffing time and level. Mechanical skiffing or plucking is, now, common in the countries, which cultivate mainly var. *sinensis* for green tea because var. *sinensis* have morphological (smaller plant size and leaves) and chemical (not-easily-fermentated) advantages compare to var. *assamica*. Tea skiffing, on the other hand, induces physical and physiological damage to trees by removing the photosynthetic source, i.e. the tea leaves.

Plucking of tea leaves decreases the carbohydrate content (dw) by 20% in large roots and 21% of the weight of new shoots in the next year (Sakai 1986). The thicker the leaf layer that is maintained from autumn to winter, the higher the content of carbohydrates (DW) stored in the tree's body that would contribute to the first flush (Sekiya *et al*. 1978). Non-skiffed leaf layer was also advantageous

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Invited Mini-Review

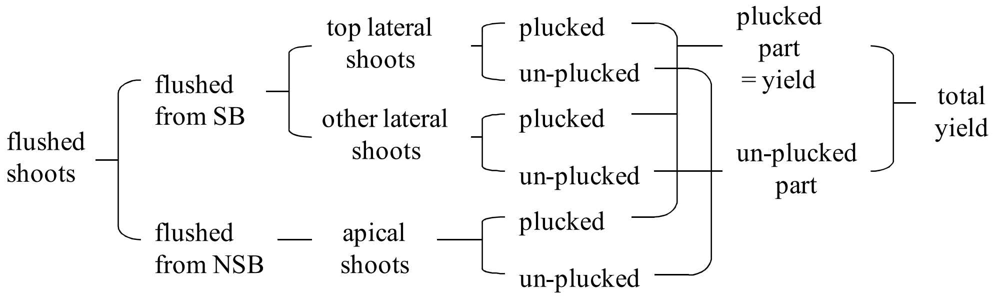


Fig. 1 Classification of flushed shoots by location concerning on skiffing and plucking.

accumulating 0.14% more nitrogen in new leaves than skiffed layer (Yamashita *et al.* 1984). These reports imply that shallow skiffing is a better option than other level of skiffing to reduce negative influences and maintain carbohydrate or nitrogen content in tea bush high.

The purpose of this review is: 1) To understand constructive change of tea bush by mechanical skiffing, 2) to analyze the precise effects of skiffing on flushing time of new shoots, yield, yield component and tea quality, and 3) to gain a basic understanding for predicting tea growth and yield after skiffing.

CONSTRUCTIVE CHANGE OF TEA BUSH BY MECHANICAL SKIFFING

The constructive changes of tea bush by mechanical skiffing were investigated in 'Yabukita' (var. *sinensis*) Japanese tea cultivar (Omae 2006). The tea plants were skiffed at three (shallow, medium and deep skiffing; skiffed at 6.0, 3.5 and 1.0 cm in height from the latest plucking surface, respectively) different levels in autumn. The leaf thickness, leaf area index (LAI) and light interception rate are measured after skiffing to evaluate tea production capability. Fresh tea yield and yield component of plucked and unplucked part in each classified branches were investigated from first to fourth crop in the following year. Chemical analysis and sensory test were conducted in first crop to evaluate quality of tea products. The surface of a tea tree changes drastically by skiffing (Omae 2006). Tea branches located on the skiffed surface are classified into two parts, skiffed branch (SB) and non-skiffed branch (NSB), by mechanical skiffing (Omae 2006). Flushed fresh shoots can be also classified into two types, apical and lateral shoots, which are flushed from NSB and SB, respectively. The lateral shoots can be classified again into several shoot types according to their position, viz. top lateral shoot, second lateral shoot, etc. When flushed shoots are mechanically harvested, the shoots can be further classified into two categories, the plucked part and un-plucked part. We usually recognize the plucked part as fresh tea yield. When we add the un-plucked part to the plucked part, we can get total yield, in which all flushed shoots are included in this category. The difference between flushed shoots after mechanical skiffing/plucking is summarized in **Fig. 1**. The two types of buds, lateral buds in SB and apical buds in NSB show different growth after skiffing. Apical buds in NSB are not influenced or poorly-influenced by skiffing, and continue to grow according to a seasonal growth cycle. Tanton (1992) reported that apical buds in var. *assamica* grow periodically and that the apical shoots, which have thicker stem, grow more periodicity than the thinner shoots. Top lateral buds in SB, on the other hand, start growing each other immediately after skiffing.

EFFECTS OF SKIFFING ON YIELD, YIELD COMPONENT AND TEA QUALITY

Mechanical skiffing influences the tree canopy and volume of tea leaves depending on the level of skiffing (Omae 2006). Deeper skiffing (1.0 cm in height from latest plucking) decreases leaf area by 41%, and the interception rate of light by 67%. Continuous shallower skiffing (October-July) results in better tea production, and a greater yield of new leaves can be expected than other skiffing levels. These advantages are clearly reflected in the green tea quality of the first crop (Omae 2006). By applying shallow skiffing, we get better tea quality in all analyzed parameters, namely total nitrogen by 19%, free amino acid by 39%, and theanin by 43% higher compared to deep skiffing, which are recognized as the components of "umami" or savoriness (Nakagawa *et al.* 1981), all of which increase. In contrast fiber content, which affects taste negatively, decreases by 15% by shallower skiffing. The results of a sensory test, which was conducted by experienced inspector, support the results of chemical components, showing that flavor, brewed colour and taste in shallow skiffing got higher scores by 17, 8 and 8%, respectively (Omae 2006). The first and second crop of medium skiffing result in the highest total shoot weight (Omae 2006) while this value only becomes greatest in third and fourth crop when shallow skiffing is used. This reason is because of fewer new shoots flushed from all branches. The total number of shoots in shallow skiffing (2476 shoots/m^2) is statistically lower than the deep skiffing (5133 shoots/m^2) treatments in first crop (Omae 2006). In the third and fourth crop, the total number of shoots increases and plateaus (4609 shoots/m^2) to the same level as medium (4778 shoots/m^2) and deep (4748 shoots/m^2) skiffing treatments. The reason why fewer shoots (2476 shoots/m^2) are flushed in shallow skiffing of the first crop is because there are fewer apical buds (4984 buds/m^2) in the NSB. When we consider the origin of NSB, we can assume it as the place, which maximum number of cut branches exist, because new tea shoots are ordinally emerged from the top buds in branches. Nakano (1998) reported that a matured tea tree, which grows 1.5-1.8 m in width (row to row size), has the maximum number of branches at the latest plucking surface. We can then assume that NSB originate from the latest plucking surface. The distance between the surface of latest plucking (the position probably maximum NSBs were emerged from) and skiffed surface in autumn, therefore should be equal of apical shoots length flushed from NSB in first crop. This distance is closer in medium skiffing (3.5 cm) compare to shallow skiffing (6.0 cm). Therefore, this implies that medium skiffing results in the maximum number of apical buds at closer position than shallow skiffing. Deep skiffing, on the other hand, results in minimum tea yield among the skiffing treatments because of poorest circumstances (smallest interception rate and LAI) for tea production, which limit shoots extension though there are a maximum number of shoots among the treatments (Omae 2006).

Mechanical skiffing also influences the ratio of flushed shoot to total shoot weight in plucked and unplucked parts (Omae 2006). The ratio in the unplucked part, which is produced by mechanical plucking, differs depending on the crop season, skiffing level and branch although no statistical differences were observed. The unplucked part to total flushed shoots weight accounts for 34-37% of the crop season. The unplucked ratio increases by deeper skiffing, and in the latter crop seasons. The unplucked ratio in apical shoots is bigger in earlier and smaller in latter crop season.

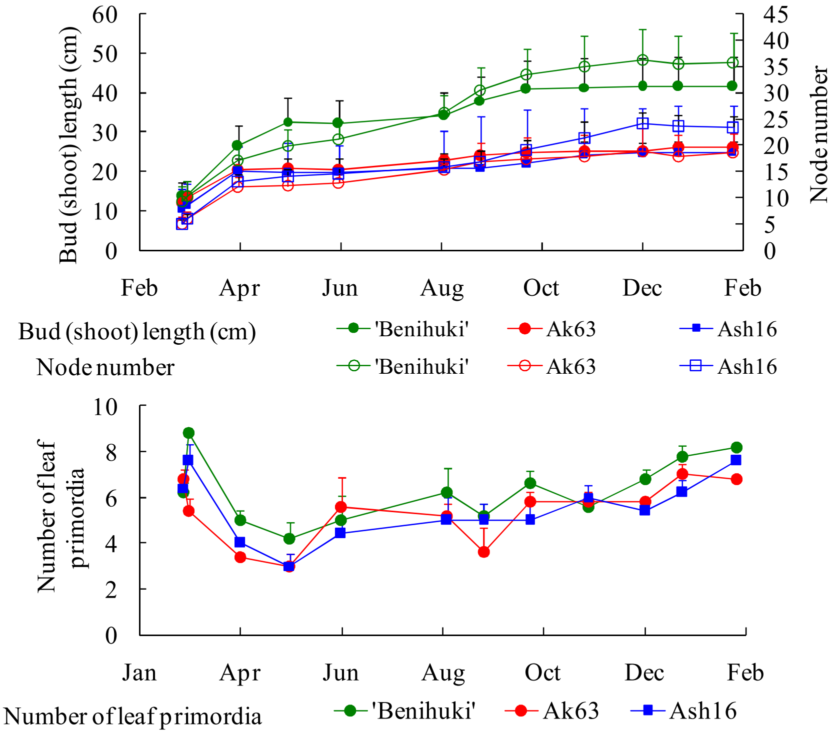


Fig. 2 Changes in the bud (shoot) length and number of leaf primordia. 'Benihuki' is a Japanese cultivar. Ak63 and Ash 16 are tea lines collected in India and Vietnam, respectively. Values represent the mean (±SD).

GROWTH HABIT OF TOP LATERAL BUDS AND PREDICTING THEIR DEVELOPMENT

Naturally grown two strains (var. *assamica*) and one cultivar (hybrid of var. *assamica* with var. *sinensis*) were used for investigating growth habit of apical buds in non-skiffed branches (Omae 2004). Apical buds in NSB show periodic growth, which starts at the end of April (**Fig. 2**). The growth in each branch is synchronous in April but become indiscriminate thereafter. The number of leaf primordia decreases from 2.4 to 4.6 depends on the cultivar as the shoot increases from 7.4 to 18.5 cm in length.

Growth habits of lateral buds in skiffed branches were observed using "Yabukita" in ordinal tea garden (Omae *et al.* 2003a). Top lateral buds in SB, on the other hand, start to grow immediately after skiffing in the following steps: 1) development of an initial bud; 2) bud break; 3) flushing; 4) stop flushing with the appearance of a banjhi bud defined as terminal leaf. The number of leaf primordia starts to increase immediately after skiffing, and continues to increase until the shoots are flush in each crop season, except for the first crop. In the first crop, in contrast, the number of leaf primordia tentatively stops increasing at the end of December and begins to increase again at end of March. Nakano *et al.* (1993) confirmed this stop in leaf primordia at the same period. The number of leaf primordia before leaf opening and at the banjhi stage are almost similar from second to autumn crop (Omae *et al.* 2003a).

Bond (1945) reported that initial buds in var. *assamica* develop with shoot extension and leaf expansion. Nakayama *et al.* (1960) explained that the reason why banjhi shoots, which are an important indicator for plucking, are produced during bud development is because the speed of leaf expansion exceeds the development of bud initiation. Flushed new leaves are harvested when 60-80% of banjhi shoots appear. The stems of banjhi shoots are eliminated with a grading machine in the process of tea manufacturing because their stems harden quickly and they reduce tea quality. Konomoto (1980) confirmed that increase of hardness in stem linearly reduced the tea quality with high correlation coefficient in four Japanese cultivars (r = -0.9945 to -0.8992). The number of leaf primordia and their relation with shoots expansion are, therefore, important because they regulate plucking time, which is determined by the appearance of banjhi shoots.

To predict the increase in leaf primordia from meteorological factors, we must find out key factors that regulate it. Temperature can be one of the key factors regulating bud growth. There are numerous reports (Harada *et al.* 1960; Nakayama *et al.* 1962, 1966; Yanase *et al.* 1972, 1975; Sekiya *et al.* 1979; Yanase *et al.* 1980, 1982) studied on the influence of temperature on shoot extension using Japanese early to late cultivars (var. *sinensis*) in Japan. Most researchers indicated that higher (above 35-40°C) or lower (bellow 5-10°C) temperature repress shoots growth. Optimum temperatures for growth are different depends on the cultivars. Early cultivars like 'Inzatsu-131' or 'Makinoharawase' grow very well above 20°C but late cultivars such as 'Yamatomidori' or 'Benihomare' grow slow at 20°C (Nakayama *et al.* 1962).

Some researchers (Squire 1979; Tanton 1982; Smith *et al.* 1993; Squire *et al.* 1993; Stephen *et al.* 1993; Burgess *et al.* 1997) investigated the influence of temperature on shoot extension or growth rate using var. *assamica* or its hybrid with var. *sinensis* on the concept of "base temperature" for tea growth. "Base temperature" means lower limit in temperature for buds growth. The concept is that each cultivar has an inherent values in temperature for starting buds growth, and, thus, can be compared each other. Day length is also another important factor for regulating tea growth. There are some reports (Mitsui *et al.* 1962; Barua 1969; Herd *et al.* 1976; Fordham *et al.* 1977; Tanton 1981) in which the influence of day length on tea growth was investigated using var. *assamica*.

Considering these reports, we designed models for predicting the development of leaf primordia. The structures of functions are based on the concept of "base temperature" or base day length (**Table 1**). Temperature and day length were used as independent variables, individually (Model 1 and 2) or with combination (Model 3 and 4) to analyze the effect of

Table 1 Models predicting for DVR[1] of total number of leaves.

Model	Functions
(1)	a ×(T-b)
(2)	a × (D-b)
(3)	a × (T-b) × (D-c)
(4)	a × (T-b) + c × (D-d)

T: Daily mean temperature (°C)
D: daylength (hr), a, b, c, d: Parameters.
[1]Developmental rate of all leaves per day.

temperature and day length, and its interaction as described by Nakano (1999). The simplex method was adopted for searching optimum values in the parameter, in which the standard error (S.E.) shows minimum value. Akaike's information criterion (AIC), on the other hand, is used for estimating the availability of parameter in the model. All designed models (**Table 1**) are applied to the data, which were taken at ordinal tea garden for all crops (first to fourth crop) using top lateral buds of skiffed branches in cv. 'Yabukita'.

Model (4), which includes daily mean temperature and day length as explanatory variables in the model, shows minimum S.E. and AIC, and fits the changes of total number of leaves in all crop seasons well (Omae *et al.* 2003b). From a comparison of the result in model (4) with that in (3), we can consider that temperature and day length act together more additively than synergistically. From a comparison of the result in model (1) with that in (2), temperature may play a more important role for development of leaf primordia than day length. The influence of day length, however, cannot be ignored when we compare AIC in model (4) with that in model (1). Prediction accuracy is improved from the middle of December to early March more in model (4) than in model (1). From this comparison, there is the possibility that winter bud dormancy is related more with day length because winter bud dormancy is included in this period (Yanase 1971; Hachinohe *et al.* 1988; Nakano *et al.* 1993). Some reports (Barua 1969; Laycock 1969) also support this consideration. The base temperature for the development of leaf primordia was simulated as 6.9°C, and base day length as 10.11 hr in model (4) (Omae *et al.* 2003b). These values are similar to the values in models (1) and (2) (8.3°C and 9.92 hr, respectively). Sekiya *et al.* (1979) reported that highest prediction accuracy for harvesting time could be achieved when it was predicted using an effective accumulated temperature above 7.6°C. Burgess *et al.* (1997) reported that the base temperature for new bud growth differed depending on the cultivar but was within 6.1-9.2°C. Barua (1969) mentioned that winter bud dormancy in tea was induced bellow 11 hr 10 minutes both in var. *assamica* and var. *sinensis*. Our results echoed these results.

PREDICTING YIELD OF TOP LATERAL SHOOTS FROM YIELD COMPONENTS

The ordinal tea garden (cv. 'Yabukita') was used to know the relationships of development of leaf primordia with shoot length and leaf expansion in top lateral shoots of four crops (first to fourth crop) (Omae *et al.* 2003a). The total number of leaves (including the number of open leaves and leaf primordia) increases logarithmically with an increase in bud (shoot) length in all crop seasons except for the latter period (after the appearance of banjhi buds) of first crop in "Yabukita" (Omae *et al.* 2003a). We can use the same logarithmic equation to predict the total number of leaves from bud (shoot) length with a high coefficient of codetermination ($r^2 = 0.911$) in the second to autumn crop. After the appearance of banjhi buds in first crop, the relationship between the total number of leaves and shoot length become linear. We assume that the reason why the relationship between the total number of leaves and bud (shoot) length is shown by a logarithmic equation is due to the different response to temperature between the development of the leaf primordia and shoot extension as Burgess *et al.* (1997) mentioned. He indicated that the base temperature for shoot extension is 1.7-3.4°C higher than that for the development of leaf primordia. The logarithmic equation is different in the first crop than the other crops. The linear relationship between the total number of leaves and shoot length after the appearance of banjhi buds in first crop (Omae *et al.* 2003a) occurs because the tea trees were shallowly skiffed in this experiment. Fewer shoots stimulate the use of photosynthetic assimilates for the development of leaf primordia; therefore, shoots can extend continuously with delayed increases of banjhi buds. Such a linear increase in the total number of leaves with shoot extension can be generally observed in fields of shallowly skiffed tea. Nakano (1998) reported that appearance and increases of banjhi shoots were delayed in shallow skiffing because less number of shoots, which occur due to skiffing, grow more greatly and continuously compared to ordinal skiffing. Plucking is, thus, often delayed in such a field. The delayed increases of banjhi buds was observed in my experiment, too (Omae 2006). The 100-shoots weight remained higher throughout the experiments than the other medium and deep skiffing treatments.

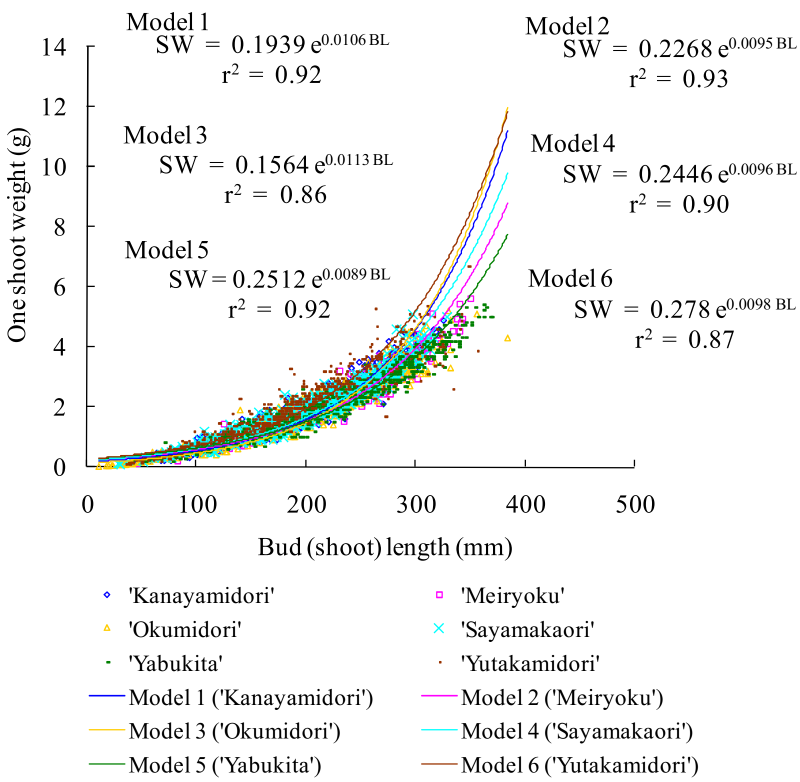


Fig. 3 Models for predicting one shoot weight from bud (shoot) length. SW: One shoot weight (g); BL: Bud (shoot) length (mm).

The relation between weight of a single shoot and bud (shoot) length in top lateral buds (shoots) of six Japanese cultivars (var. *sinensis*) at a shallow-skiffed tea garden (Omae 2004). The weight of a single can be predicted from bud (shoot) length with a simple exponential equation (**Fig. 3**). The equation was selected by the comparison of the other linear or logarithmic equation because showing the best compatibility. Parameters of each cultivar were determined individually by least-square approach. Each Japanese cultivar has an inherent value in each equation on determination of the equation. The number of flushed top lateral shoots in SB can be easily predicted from the number of SB with a simple linear regression with a higher ($r^2 = 0.62$) coefficient of codetermination (**Fig. 4B**).

By using the above relationships, we can create an image of the processes for predicting tea yield from the development of leaf primordia via the relation of total number of leaves with the number of SB (**Fig. 4B**), bud (shoot) length (Omae *et al.* 2003a), the relation of bud (shoot) length with one shoot's weight (**Fig. 3**), and the results of the prediction of bud development (Omae *et al.* 2003b) in top lateral shoots of SB. We can use the number of SB as an independent variable in the model for predicting the total number of shoots (**Fig. 4B**) because we can easily count the number of SB from the skiffed surface of tea tree visually. The number of apical buds in NSB or the total number of flushed shoots, on the other hand, are more difficult to predict from the number of SB because they have lower coefficients of codetermination ($r^2 = 0.31$ and $r^2 = 0.33$, respectively; Omae *et al.* 2003a).

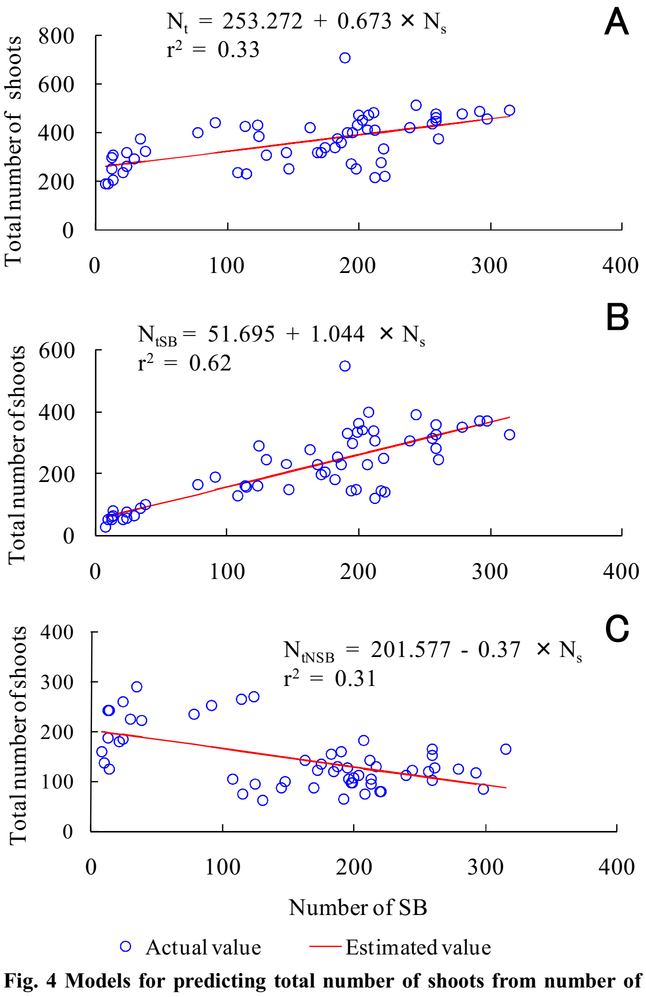


Fig. 4 Models for predicting total number of shoots from number of SB. A: total number of shoots in both SB and NSB; B: Total number of lateral shoots from SB; C: total number of apical shoots from NSB; N_t: total number of shoots x 900 cm^{-2}; N_s: number of SB x 900 cm^{-2}; N_{tSB}: total number of lateral shoots from SB x 900 cm^{-2}; N_{tNSB}: total number of apical shoots from NSB x 900 cm^{-2}.

PREDICTING YIELD OF TOP LATERAL SHOOTS FROM METEOROLOGICAL FACTORS

Crop yield is generally regulated by meteorological factors if some other factors like nutrients are supplied enough to the crops. Carr *et al.* (1992) mentioned the major limiting factors which regulate tea yield are solar radiation, temperature, water saturation deficit and soil water. The difficulties in predicting tea yield are that fresh tea leaves are grown in a very limited period of long life span and harvested only non-lignified parts of fresh leaves. So, we should specify the period which meteorological factors affects the tea yield and also specify the parts harvested. The new leaves emerged from skiffed branch has an advantage on this point, because we can detect the starting period for growing by skiffed date and assume the position and plant parts to be harvested (Omae 2006).

For predicting yield of lateral and apical shoots, six Japanese cultivars (var. *sinensis*) were skiffed with 22 days intervals (average) for 13 times in a year, and investigated yield and yield components in skiffed and non-skiffed branches, separately. Meteorological data, which were taken at the same time, were used to see the relationship with yield of lateral and apical shoots, and also for predicting these yields (Omae 2004). There are differences in the correlation between total yield and meteorological factors by branches. All meteorological factors show the highest relationship with yield in the top lateral shoots of SB than in other branches (**Table 2**). The other lateral shoots without top lateral shoots in SB also showed higher correlation coefficients with meteorological factors than apical shoots. The total yield of apical shoots in NSB have no relationship with the meteorological factors. From these results, we searched independent variables which showed best fitness for predicting tea yield of top lateral shoots by forward selection method. All meteorological factors shown in **Table 2** were used for the creation of the best fitting model. As result, a multiple regression model, which is composed by four independent variables (days after skiffing, accumulated daily maximum temperature, accumulated daily minimum humidity and accumulated solar radiation) was created for predicting fresh shoot weight of top lateral shoots in SB with a high ($r^2 = 0.52$) coefficient of codetermination (**Fig. 5**). The values for "Time" is calculated by subtraction of plucking to skiffing date in each crop season. The values of daily maximum temperature, minimum humidity, and solar radiation from skiffing to harvesting were integrated for the calculation of "T_{max}", "H_{min}" and "R", respectively.

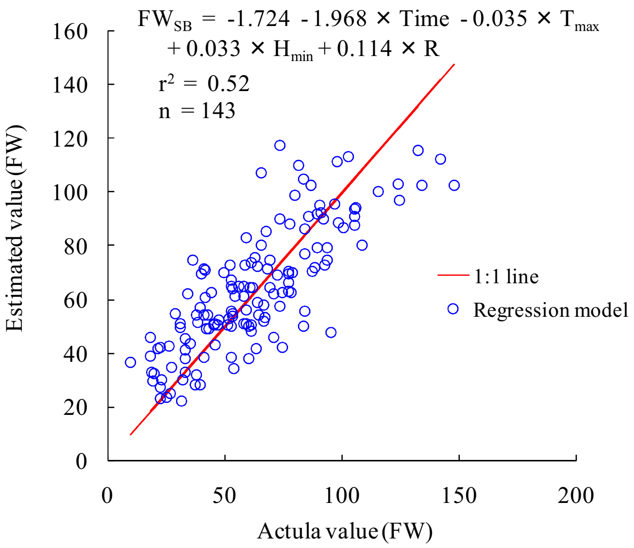
It is worthy to note that the multiple regression equation for tea yield of top lateral shoots includes two minus parameters on days after skiffing ("Time") and accumulated daily maximum temperature ("T_{max}"). This indicates that these two factors work negatively against fresh shoot weight. We assume that the "Time" factor has a role to depress bud growth, especially in winter. When we compare actual values of the "Time", days after skiffing is bigger in the corresponded periods of first crop (average value is 138 ± 44 days) than in the periods of second and third crops (42 ± 1 and 40 ± 0 days, respectively). It means that the negative impact of this factor is bigger in the first crop, which includes a period of winter bud dormancy, which does not occur in the other crops. Photosynsystem II activity of overwintered leaves was depressed by 70% by low temperature (Aoki 1986). Sakai (1986) also mentioned that carbohydrates stored during winter were mainly used to maintain the tree body and only 10% was used for shoot flush. The "Time" factor, in this way, seems to play a role in the evaluation of negative influences on tea yield in winter such as depression of bud growth, photosynthesis and a lower mobilization of stored carbohydrates to new shoots. As for the factor "T_{max}", Harada *et al.* (1957) mentioned that high temperature (>35°C) decreased the quantity in carbon assimilation.

As a positive effect to tea yield, the accumulated daily minimum humidity ("H_{min}") is included in the function.

Table 2 Correlation between total yield and meteorological factors.

	Total yield	Days after skiffing	Accumulated daily mean temperature (°C)	Accumulated daily maximum temperature (°C)	Accumulated daylength (h.)	Accumulated solar radiation (J)	Accumulated daily minimum humidity (%)
SB	Top lateral shoots	0.51**	0.49**	0.49**	0.52**	0.49**	0.56**
	Other lateral shoots	0.41**	0.39**	0.40**	0.40**	0.42**	0.38**
NSB	Apical shoots	0.07	0.03	0.04	0.07	0.09	0.07
	Total	0.44**	0.41**	0.42**	0.45**	0.45**	0.46**

** indicates significantly different at 1% level.



Figs. 5 Model for predicting the total yield from meteorological factors in SB. FW_{SB}: total fresh shoots weight (g) in a 30 × 30 cm^2 frame in SB; Time: days after skiffing; T_{max}: accumulated daily maximum temperature (°C); H_{min}: accumulated daily minimum humidity (%); R: accumulated solar radiation (J).

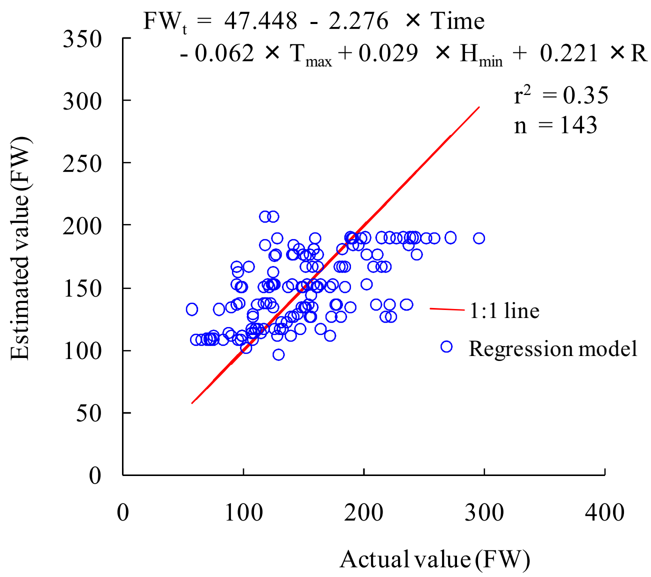


Fig. 6 Models for predicting total yield from meteorological factors. FW_t: total fresh shoots weight (g) in 30 × 30 cm^2 frame in both SB and NSB; Time: days after skiffing; T_{max}: accumulated daily maximum temperature (°C); H_{min}: accumulated daily minimum humidity (%); R: accumulated solar radiation (J).

There are many studies that indicated that vapor pressure deficit in the day time is one of the important factors depressing shoot extension (Carr 1972). The effect of rainfall on buds growth was also reported by several researchers (Kuranuki 1987; Kume *et al.* 1994) using Japanese cvs. 'Yabukita' or 'Sayamakaori'. Both of them agreed that rainfall hasten the flushing time of both apical and lateral buds in first crop although period and effect of rainfall are different depends on the authors. A lower minimum humidity, thus, seems to negatively impact to tea growth in the model.

PREDICTING TOTAL YIELD FROM METEOROLOGICAL FACTORS AND THE YIELD COMPONENT

For predicting total yield from meteorological factors, the both of the yield of lateral and apical shoots in six Japanese cultivars (var. *sinensis*) with 13 times skiffing (22 days interval on average) in a year were used for this purpose (Omae 2004). The coefficient of codetermination using a multiple regression model for predicting total yield is lower (r^2 = 0.35; **Fig. 6**) than that of the model used to predict the yield of top lateral shoots (**Fig. 5**) because total yield includes the yield of apical shoots, which has no relation with the meteorological factors (**Table 2**). The prediction accuracy of this model, however, drastically increases when the total number of buds was added into the independent variables (r^2=0.50; **Fig. 7**). The number of flushed shoots, which is one of the yield components, is predictable from the number of SBs, although the accuracy rate is low (r^2=0.33; **Fig. 4A**). Total yield, in this manner, is difficult to predict directly from metrological factors. We, thus, should explore other means to predicting total yield like examining the close relationship between the number of flushed shoots and the number of SB.

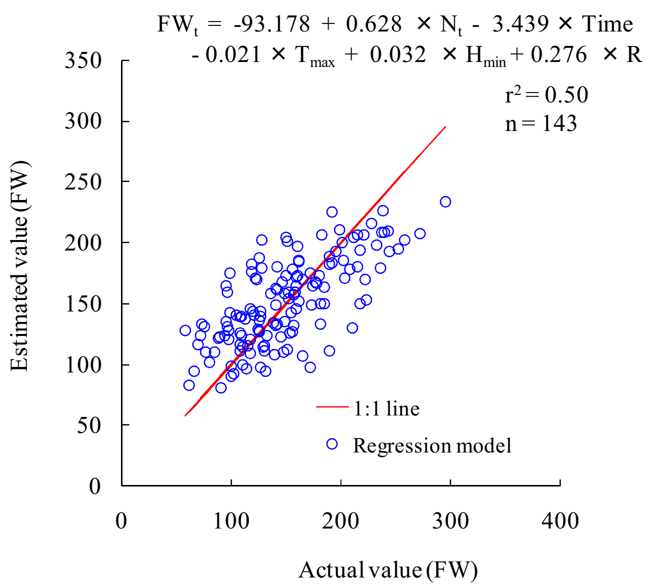


Fig. 7 Models for predicting total yield from meteorological and structural factor. FW_t: total fresh shoots weight (g) in 30 × 30 cm^2 frame in both SB and NSB; Time: days after skiffing; T_{max}: accumulated daily maximum temperature (°C); H_{min}: accumulated daily minimum humidity (%); R: accumulated solar radiation (J).

APPLICATIONS AND FUTURE PERSPECTIVES

Tea is an exceptional case for predicting total yield from other crops because 1) Non-lignified-leaves in skiffed woody plants, which are grown in limited periods (one to six months) of long-life are harvested, 2) Non-lignified-parts of leaves are harvested thorough the process of vegetative growth, not like other woody plants like fruit trees (they harvest reproductive parts). The precise prediction of total yield in skiffed tea is, therefore, very difficult without understanding the skifffed structure of tea bush and yield components in both of skiffed and non-skiffed branches. In this study, the skiffed structure of Japanese cultivar (var. *sinensis*) was firstly identified by the classification of skiffed and non-skiffed branches, and conducted detailed analysis of buds growth, which are emerged from classified branches, and clarified the possibility of precise prediction of total yield using meteorological or physical factors relating the tree structure of skiffed tea. My classification and application method for yield prediction, developed in this study, are useful for analyzing more detail of skiffed tree structure and precise prediction of tea yield. These methods also can be applicable to var. assamica, which are cultivated in oversea countries such as India, Sri Lanka, Kenya, Malawi and so on for black tea.

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JAPANESE ABSTRACT

チャの整枝は茶の生産に功罪両方の影響を及ぼす。整枝によって私たちは樹冠、摘採割合、茶の品質、新芽収量や収量構成要素を制御できる。一方、整枝自体は光合成ソースを減少させる。従ってこのトレードオフの関係やそれにどう対応していくかを学ぶことが必要となってくる。茶の生産にとって望ましい樹冠は浅整枝によって作り上げることができる。浅整枝によって一番茶の品質が良く後半の茶期での収量が多くなる。整枝によって切り取られた枝に着生する第１側芽の発達は、日平均気温と日長から推定可能である。第１側芽の茶収量は気象要因と密接に関係しているため、整枝後の日数、日最高気温、日最低湿度や日射量の積算値を説明変数とする重回帰式により容易に推定できる。新芽の総収量は、整枝によって切り取られた枝の数から推定可能な新芽数を説明変数に加えることにより予測精度が向上する。このレビューはチャの整枝が樹冠に及ぼす影響を明らかにするとともに、整枝によって切り取られた枝の発育が、茶収量を予測する上で重要であることを示す。