Research Article
Journal of Plantation Crops, 2013, 41(2): 136-141

Impact of continuous mechanical harvesting on the carbohydrate dynamics and architectural characteristics of tea plants

Siby Mathew*, R. Raj Kumar[1], M. Marichamy, R. Shanmugapriyan and P. Mohan Kumar[1]

*UPASI Tea Research Foundation, Regional Centre, Vandiperiyar-685533
[1]UPASI Tea Research Foundation, Tea Research Institute, Valparai-642127

(Manuscript Received: 01-01-13, Revised: 26-03-13, Accepted: 10-04-13)

Abstract

Tea is a labour intensive plantation crop and management of crop husbandry practices has become difficult due to the scarcity of labour. In order to improve the labour productivity and to attain positive cost benefits ratio, management of tea estates are forced to adopt mechanization as a routine cultural operation. In the present study, carbohydrate dynamics and bush architecture of machine harvested fields are studied in comparison to integrated shear harvested fields. Continuous mechanization registered relatively lower levels of phytomass. Recovery from pruning was delayed in the mechanically harvested fields. Yield and yield attributes were significantly higher in the integrated shear harvested fields compared to mechanical harvesting. Carbohydrate dynamics of both the fields indicated low level of total carbohydrate, starch and reducing sugars in the root. Replenishment of carbohydrate showed a similar pattern in both the fields. No major variation was observed between the treatments for photosynthetic carbon dioxide assimilation rate and pigment concentration. Leaf constituents like polyphenols, catechins and amino acids of crop shoots did not show major variations. Soil biota was less in the mechanically harvested fields. The data generated from this experiment will lead to advanced research on mechanization and to develop suitable agro-technologies.

Keywords: Carbohydrate, mechanization, phytomass, shear harvesting, yield potential

Introduction

India produces approximately 980 million kg of made tea annually and is the second largest producer of black tea in the world. About 27 per cent of the world's tea is produced in India and is also the largest consumer of tea accounting for about 22 per cent of total world consumption. Tea plantations provide employment to more than a million workers who comprise immigrant workers and their descendants. More than 50 per cent of the workers in tea estates are women (Arya, 2007). India has been producing tea for more than 150 years and occupies second position next to China as a largest tea producing nation (Year book of UPASI 2011-12). South Indian tea industry contributes around 25 per cent of Indian tea production. The Indian tea industry today is experiencing crisis arising out of a high degree of competition in international markets, resulting in stagnation and/or decline in prices. On the other hand, yield level of tea gardens have declined due to ageing of tea bushes which has also resulted in deterioration in quality leading to further decline in prices. Due to these factors, tea industry is experiencing a phase of declining profitability. Scarcity of labour for harvesting tea levels is yet another constraint in most of the tea growing region of South India. Shear harvesting was adopted to mitigate scarcity of labour; consequently integrated system of harvesting was recommended (Satyanarayana *et al.*, 1990). However, continuous shear harvesting was attempted in most of the tea growing regions to manage labour scarcity. In the recent times, even continuous shear harvesting throughout the year was unable to mitigate scarcity

*Corresponding Author: sibymathew3@gmail.com

of labour. Mechanization of harvesting with the help of double and single men operated models were tried during late 1990s (Illango *et al.*, 2001). Extensive mechanization of harvesting was adopted from 2005-06 onwards (Ajaikumar, 2009). Most of the estates in south India will be forced to uses machines in near future without which efficient harvesting is impossible during the high cropping season (Ajaikumar, 2009; Durairaj, 2009).

Mechanical harvesting is a non-selective operation that hampers photosynthetically active maintenance foliage. Catabolic activity and respiration will be high in mechanical harvested fields (Marimuthu *et al.*, 2001; Illango *et al.*, 2001; Raj Kumar *et al.*, 2010). Initial studies on carbohydrate dynamics and recovery from mechanically harvested fields have indicated significant variation in carbohydrate levels and its replenishment (Mathew, 2010). The present study deal with impact of mechanization on the recovery, carbohydrate dynamics and yield attributes which will act as a basic study for the advanced research on mechanization to develop suitable agro-technology.

Materials and methods

This non-replicated observational study comprised of two large blocks of (one acre area) of tea at Pasuparai estate of M/s. A.V. Thomas & Co. Ltd. The experiment fields was newly planted (1998) with clone UPASI-9 and formative pruning was done in 2004. The experiment comprised of two treatments *viz*. mechanization of harvesting and integrated shear harvesting. The field selected for mechanization was under regular mechanical harvesting from 2006 onwards. The field selected for comparison (control) was under integrated shear harvesting during the high cropping months and normal hand plucking was done during the lean periods. Both the fields were pruned during 2009 as per the recommendation of UPASI TRF (Muraleedharan *et al.*, 2007). Root samples were collected prior to pruning for carbohydrate quantification. Root samples were collected at quarterly interval after pruning and subjected to carbohydrate estimation. Data on biometric parameters were collected at the time of pruning. Recovery process of both the treatments was studied from sprouting till tipping and unfolding of every leaf. Yield and yield attributes were monitored at every round of plucking. Crop harvested was converted into made tea at an out-turn of 22.5 per cent on the basis of bush population. Phytomass (uneconomic plant parts) removed at the time of pruning (maintenance foliage/branch) was quantified with a metric balance. Yield potential (the ratio between the yield of the treatments and the mean yield of the fields) was computed every year. All agricultural operations were carried out as per the recommendation of UPASI TRF (Muraleedharan and Hudson, 2007).

For the estimation of carbohydrate, pencil thick roots were collected at random from different bushes and dried in a hot air oven at 65 °C for 24 hours. Dried samples were pulverized in Willy mill and powdered samples were used for estimation of carbohydrate as per the method of Sadasivam and Manickam (1996). Besides the total carbohydrate, reducing sugar and starch were quantified using the above methods with anthrone reagent. Tea shoots comprising three leaves and a bud collected from the experimental plots were subjected to biochemical constituents like polyphenols (Dev Choudhury and Goswami, 1983), catechins (Swain and Hillis, 1959), amino acids (Moore and Stein, 1948) and chlorophyll content (Arnon, 1949) following the standard procedures.

Soil samples were collected at periodic interval and enumeration of microflora such as bacteria, fungi, actinomycetes, azosprillium, phosphate soluble bacteria (PSB), *Pseudomonas* and *Trichoderma* were done as per the standard procedure (Gordan *et al.*, 1973; Martin, 1950; Kuster and Williams, 1964; Dobereiner and Dey, 1976; Pikovskaya, 1948; Cochran, 1950 and King *et al.*, 1954). Number of colonies formed were counted and expressed as number of colony forming units per gram of dry soil.

Results and discussion

Extensive mechanization reduced canopy area compared to integrated shear harvesting (Table 1). Reduction in crop and loss of maintenance was reported when shear harvesting was done continuously (Marimuthu *et al.*, 2001). Phytomass

Table 1. Biometric parameters of continuously machine harvested and integrated shear harvested fields (recorded at the time of pruning)

Parameters	Mechanical harvesting	Integrated shear harvesting
Canopy area ha^{-1} (m^2)	8609 ± 1248	9715 ± 771
Phytomass (t ha^{-1})	22.2 ± 2.0	29.1 ± 3.0
Wt. of stem (t ha^{-1})	16.5 ± 1.5	18.4 ± 1.9
Wt. of leaf (t ha^{-1})	5.7 ± 1.4	10.6 ± 1.9
Leaf to stem ratio	0.35 : 1	0.58 : 1
Depth of maintenance foliage per bush (cm)	15 ± 2.0	29.8 ± 4.0

and leaf stem ratio was also lower in the machine harvested fields compared to control (Table 1). Regular hand plucking with judicious addition of mother leaf every year will lead to a leaf stem ratio of 1:1 at the time of pruning (Satyanarayana and Sharma, 1984). Reduction in leaf stem ratio in both mechanical and sheared fields indicated debilitation in bush health. Depth of active maintenance foliage of mechanical harvested fields was only 15 cm whereas around 30 cm depth of maintenance foliage was noticed in the control (Table 1). Generally, depth of maintenance foliage above 20 cm is ideal for sustainable crop production from tea (Manivel, 1999). Suppression in the phytomass load adversely affected on the recovery of the bushes. Considerable delay in sprouting and unfurling of leaves and delayed tipping was noticed in the mechanized fields (Table 2). A similar pattern was reported earlier by Mathew (2010) in the machine and shear harvested fields. Continuous mechanical harvesting depleted root reserves significantly compared to integrated shear harvesting (Table 3 and Fig. 1). It is evident from Table 3 that reducing sugar and starch also declined significantly prior to pruning (pre-treatment). The total carbohydrate attained pre-pruned level in about three months in both the treatments, while starch and reducing sugars

Table 2. Recovery of bushes from pruning by mechanization and integrated shear harvesting

Parameters	Mechanical harvesting	Integrated shear harvesting
Sprouting (days)	35 ± 4	25 ± 3
Unfolding of first leaf (days)	43 ± 2	37 ± 3
Unfolding of second leaf (days)	57 ± 2	49 ± 4
Unfolding of third leaf (days)	75 ± 4	58 ± 5
Unfolding of fourth leaf (days)	88 ± 4	74 ± 3
Tipping (days)	103 ± 6	86 ± 3

Table 3. Root carbohydrate dynamics in integrated shear and machine harvested fields

Period	Reducing sugar (%)		Starch (%)	
	Mechanical harvesting	Integrated Shear harvesting	Mechanical harvesting	Integrated shear harvesting
Pre treatment	4.81 ± 0.16	5.02 ± 0.14	9.52 ± 0.39	10.01 ± 0.31
After 3 months	5.08 ± 0.08	5.67 ± 0.23	8.73 ± 0.81	10.10 ± 0.55
After 6 months	5.19 ± 0.15	5.94 ± 0.33	8.91 ± 0.07	9.61 ± 0.50
After 9 months	5.28 ± 0.01	6.00 ± 0.13	9.17 ± 0.08	9.95 ± 0.68
After 12 months	5.43 ± 0.17	6.37 ± 0.13	9.22 ± 0.11	10.84 ± 0.14
After 18 months	5.66 ± 0.33	6.57 ± 0.06	9.33 ± 0.41	11.12 ± 0.31
After 21 months	5.64 ± 0.20	7.17± 0.32	9.96 ± 0.09	11.36 ± 0.28
After 24 months	5.85 ± 0.11	7.10 ± 0.25	10.14 ± 0.11	12.03 ± 0.31
After 28 months	7.48 ± 0.29	8.45 ± 0.17	11.86 ± 0.16	13.30 ± 0.23
After 32 months	7.49 ± 0.07	8.42 ± 0.06	11.94 ± 0.09	13.43 ± 0.24
After 36 months	7.52 ± 0.12	8.48 ± 0.21	11.16 ± 0.12	13.13 ± 0.13

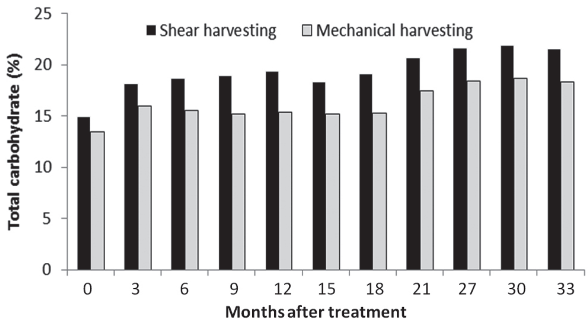

Fig. 1. Root carbohydrate dynamics in mechanical harvested and integrated shear harvested fields

attained pre-pruned level in about 6 months from pruning. Gradual increase in carbohydrate and its components was noticed thereafter in both the treatments. However, the levels of carbohydrate and its components were always lower in the machine harvested fields throughout the period of experimentation compared to the control.

Studies on the impacts of shear harvesting on bush physiology of tea by Marimuthu *et al.* (2001) indicated that shear harvesting throughout the year depleted root reserves significantly when shearing was followed up to ninth month. Carbohydrate level dropped 12.5 to 20 per cent under continuous shearing. Further, extensive shear harvesting reduced the load of maintenance foliage and leaf stem ratio. It was reported that yield depression under continuous shearing was due to increased respiratory loss, low levels of carbohydrate in root and imbalanced promoter: inhibitor ratio of mature leaves. Illango *et al.* (2001) reported reduction in crop due to mechanical harvesting. The present study on leaf stem ratio (Table 1) and delayed recovery (Table 2) confirms that findings of earlier investigations on the importance of maintenance foliage in carbohydrate reserves in tea for the sustainable production.

Crop production from the experimental fields is presented in Table 4. Tipping weight was less in the mechanical harvested fields compared to integrated shear harvesting. A similar trend was observed in the cropping pattern up to third agricultural year. Cumulative yield of mechanically harvested field was 17,854 kg made tea ha^{-1} which is lower by 1630 kg ha^{-1} (deficit of 12%) compared to integrated shear harvested fields. Although, yield potential was higher than 1.0 in both the treatments, significant variation was observed between the treatments throughout the year. Higher yield potential indicate maximization of crop production and better utilization or compartmentalization of photosynthates towards the economic crop (Raj Kumar *et al.*, 2000). Reduction in the total yield and reduced yield potential of mechanized fields can be correlated with suppression of root reserves (Marimuthu *et al.*, 2001). Carbohydrate level in the machine harvested fields was low prior to pruning which would have hampered movement of photosynthates towards the economically important crop shoots. Banji to shoot ratio was high in the machine harvested fields compared to control. Higher shoot weight was noticed in the control block right from tipping (Table 4). Proliferation of banjis in shear harvested and machine harvested fields was reported earlier (Marimuthu *et al.*, 2001; Illango *et al.*, 2001; Illango *et al.*, 2012). Ajayakumar and Vinod Haridas (2002) reported after effects of mechanical harvesting in bush health. Reduction in shoot size and proliferation of banji is confirmed in the present study also.

Table 4. Yield attributes of different systems of harvesting

Parameters	Mechanical harvesting	Integrated shear harvesting
Tipping wt. (Green leaf kg ha^{-1})	435	494
Yield (kg ha^{-1} made tea)		
First agricultural year	4091	4549
Second agricultural year	6660	7467
Third agricultural year	7103	7468
Cumulative yield	17854	19484
Banji to shoot ratio		
First agricultural year	50:50	60:40
Second agricultural year	80:20	50:50
Third agricultural year	90:10	80:20
Yield potential (Y P)		
First agricultural year	1.18	1.32
Second agricultural year	1.28	1.43
Third agricultural year	1.41	1.48
Cumulative Y P	1.30	1.42
Shoot wt. (g)		
First agricultural year	1.02	1.10
Second agricultural year	0.80	0.92
Third agricultural year	0.62	0.75

Impact of mechanical harvesting on the soil microflora is presented in Table 5. There was no major change noticed in microflora during the period of experimentation. Marginal decline in photosynthetic assimilation of carbon dioxide was observed in the machine harvested fields compared to control. Reduction in functional maintenance foliage would have hampered efficiency of photosynthesis in the plant system.

Table 5. Soil biota and photosynthetic pigments from different systems of harvesting

	Mechanical harvesting	Integrated shear harvesting
Soil biota (cfu g^{-1} of top soil)		
Bacteria ($x10^6$)	8.4	8.6
Fungi ($x10^5$)	2.4	2.9
Actinomycetes ($x10^6$)	3.6	4.3
Trichoderma ($x10^5$)	1.2	4.3
Azosprillium ($x10^6$)	0.1	0.8
PSB ($x10^6$)	2.4	8.8
Pseudomonas ($x10^4$)	1.2	1.4
Photosynthetic rate (µmol $m^{-2}s^{-1}$) (24 months)	8.23	8.28
Chlorophyll-a (mg g^{-1} fr. wt.)	2.26	2.27
Chlorophyll-b (mg g^{-1} fr. wt.)	0.87	0.88
Total chlorophyll (mg g^{-1} fr. wt.)	3.35	3.38
Chlorophyll a:b	2.60	2.58
Carotenoids (mg g^{-1} fr. wt.)	1.14	1.15
Polyphenols (%)	28.9	28.6
Catechins (%)	18.8	19.1
Amino acids (%)	2.35	2.33

Photosynthetic pigments and chlorophyll a:b ratio did not show much variation among the treatments. Similarly, concentration of polyphenols, amino acids and catechins also did not exhibit significant variations. Illango *et al.* (2012) recommended a special foliar application schedule for the mechanical harvested fields. According to them, addition of plant growth hormone gibberellic acid (GA_3) is beneficial to reduce banjification and other adverse impact of mechanization. Raj Kumar *et al.* (2011) recommended addition of a growth regulator Kadostim 20 along with micronutrient formulation. Foliar application KNO_3 to reduce leatheriness of leaf in continuous sheared fields was reported by Thomas *et al.* (2008). The present study did not exhibit any major changes in photosynthetic pigments, polyphenols and amino acids in the plant system in the machine harvested fields compared to control. This showed that the adverse effects of mechanization can be minimized with the adoption of suitable agro techniques, especially foliar application of micro, macro nutrients and plant growth regulators (Raj Kumar *et al.,* 2011; Illango *et al*., 2012).

In nutshell, the present comparative study confirmed that vegetative growth of tea bushes are suppressed with regular mechanization which will affect adversely on the architecture of the bush and economically important crop production. The importance of leaf addition, maintenance of bush creep and development of suitable agro techniques for mechanized fields was revealed in the study.

Acknowledgement

We thank the management of Pasuparai estate, M/s. A.V. Thomas & Co. Ltd. for permitting us to conduct the experiment.

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