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Evaluation of the Impacts of Mechanical Harvesting on Tea Yield (Cultivar TRI 2027) in the Low Country of Sri Lanka

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ABSTRACT

Due to worker shortage in the plantation sector of Sri Lanka, timely maintenance of plucking rounds has become a difficult task for the tea growers. As a result, the abandonment of tea fields has become a common practice in the estate sector. Harvesting, the most labour intensive field operation in tea cultivation has adversely affected under worker scarce situations. Although, motorized harvesting is the apparent alternative to manual harvesting when the labour supply is limited, the drastic yield and quality reductions and deterioration of health of tea bushes limit the use of machines for harvesting. Such downsides are reported to be resulted from three basic impacts, viz. removal of arimbu (immature) shoots, higher severity of harvesting and removal of maintenance foliage. Hence, a detailed study was carried out to quantify the contribution of each impact for yield reduction under mechanical harvesting.

Results showed that the greatest impact in the yield reduction was exerted by removal of arimbu shoots (55%) followed by higher severity of harvesting (15%) and removal of maintenance foliage (12%). The removal of arimbu shoots and maintenance foliage adversely affect the sink: source relationship of the bush and thus, photosynthesis. This reduces available carbohydrates for growth and affects branch (vascular system) development and thus, the translocation capacity of the bush. Insufficient carbohydrates and poor translocation capacity result in low shoot density and shoot weight, higher dormancy, reduced root starch reserves and consequently reduction in yield. Use of machines only during cropping months, avoiding a deep cut into the plucking table and good agronomic practices minimizing environmental stresses were identified as remedial measures arresting yield losses.

Keywords: *mechanical harvesting, physiology, tea, yield decline*

INTRODUCTION

Tea industry contributes to 0.7% of the national GDP (Anon., 2018) and provides livelihood to about 2.5 million people (Anon., 2010). As a result of severe labour shortage in the tea growing sector, timely harvesting has become extremely difficult. This has led to extension of plucking rounds and abandonment of tea fields. Further, it was reported that country's tea land extent has reduced by 3.4% during a 5-year period from 2002 to 2008 (Samansiri *et al.*, 2011).

Manual harvesting is the most affected field operation due to worker shortage as the highest labour intensive field operation in tea cultivation, contributing to about 70% of the field labour requirement. The motorized harvesters have become the only alternative for manual harvesting (Wijeratne, 2003; Madamombe *et al.*, 2015). However, continuous machine harvesting has resulted drastic yield and quality reductions, poor health of tea bushes and poor recovery after pruning (Nandagopalan *et al.*, 2014; Kunyanga, 2017; Bolten, 2015; Kitur and Rop, 2016). These drawbacks were found to be resulted from three basic mechanical impacts, *viz.*, indiscriminate removal of *arimbu* shoots, removal of maintenance leaves and higher severity of harvesting (Madamombe, 2008; Wijeratne, 2012; Pathiranage *et al.*, 2016). Nevertheless, some tea growing countries in the Mediterranean region such as Japan and China are using motorized harvesting machines successfully. Since, the labour shortage is expected to be more severe in years to come, it is necessary to identify ways and means of minimizing yield losses caused by motorized tea harvesters. In this regard, actual contribution of above impacts towards yield reduction needs to be quantified. Hence, the present study was carried out with the objectives of quantifying the contribution of mechanical impacts on tea yield reduction and identifying their physiological bases.

MATERIALS AND METHODS

The experiment was conducted at St. Joachim estate, Ratnapura (6°40' N, 80°23' E; 30 m *amsl*; rainfall >3200 mm yr^{-1}; Agro-ecological region WL1a), using tea (*Camellia sinensis*) cultivar TRI 2027 in its second year after pruning. In a previous field trial of one year (Pathiranage, 2019 – unpublished data), three basic effects of mechanical harvesting were quantified separately (Table 1).

Table 1. Impacts of Motorized Mechanical Harvesting (MMH) as quantified in a previous experiment

Impacts of MMH	Quantity (count/bush/fortnight)
Removal of maintenance foliage	30 half-cut leaves (=15 leaves)
Removal of *arimbu* (immature) shoots (number of shoots)	
Only the buds	18
Buds with fish leaf	11
Buds with one leaf	12
Total removal of arimbu shoots	**41**
Severity of MMH (number of shoots)	
Cut immediately below fish leaf	28
Cut immediately above fish leaf	15
Leaving a mother leaf	10
Leaving 2 leaves	4
Total shoots removed	**57**

Values presented are averages of 24 fortnight intervals; Source: Pathiranage, (2019) - unpublished data.

In this experiment, following effects were simulated manually as treatments, *viz.:* T_1) manual 7-day harvesting [control 1], T_2) motorized 14-day harvesting using Kawasaki tea harvester - model NV60H [control 2], T_3) manual 7-day harvesting + simulating removal of maintenance foliage, T_4) manual 7-day harvesting + simulating removal of arimbu shoots T_5) manual 7-day harvesting + simulating severity of harvesting T_6) manual 7-day harvesting + all the three simulations combined. All simulations were done manually at 14-day intervals (as machine was used at fortnight intervals) using a pair of scissors. In T_3, 30 leaves were half cut (equals to removal of 15 full leaves) representing the cutting blades of the harvester. The simulations were applied separately on each tea bush. Treatments were arranged in Randomized Complete Block Design (RCBD) with four replicates per treatment. Data recordings were carried out on fresh shoot yield and growth and yield degerming factors such as shoots compositions (both in plucking table and harvested crop) girth of secondary branches, root starch contents (Krishnapillai *et al*., 1992) and leaf thickness (SLW) (leaf dry weight divided by leaf area), while adopting recommended agronomic practices during a period of one year. Data analysis was done with SAS 9.1 package using ANOVA, CATMOD/PROBIT procedures.

RESULTS AND DISCUSSION

Removal of Maintenance Foliage (RMF) and Higher Severity of Harvesting (HSH) simulated separately, showed comparable tea yields with manual harvesting which were significantly (p=0.0146) higher than other treatments (Table 2). Motorized Mechanical Harvesting (MMH) reported the lowest made tea yield which was comparable to Removal of *Arimbu* Shoots (RAS) and Combined Simulations (CS). Removal of *arimbu* shoots solely contributed to 54.71% of the total yield reduction followed by HSH (14.52%) and RMF (12.08%), compared to manual harvesting. However, CS contributed to 54.76% of the yield reduction while for the MMH it was as high as 62.85%.

Table 2. Made tea yield (kg ha^{-1} yr^{-1}) under different treatments

Treatment	**Yield** (kg ha^{-1} yr^{-1})
Manual	5142.8^{a}
MMH	1910.1^{c}
RMF	4521.2^{a}
RAS	2329.0^{bc}
HSH	4396.0^{ab}
CS	2326.5^{bc}

Means with the same letter are not significantly different at p=0.05. Each mean is derived from 4 replicate plots each consisted of 20 bushes. Tea yields above are extrapolations into one hectare (12500 bushes) considering an out turn of 21.5. MMH = Motorized Mechanical Harvesting, RMF = Removal of Maintenance Foliage, RAS = Removal of Arimbu Shoots, HSH = Higher Severity of Harvesting and CS = Combined Simulations

Manual harvesting has resulted in the highest shoot density (p<0.0001) which can be attributed to the minimum physiological stress and maximum photosynthetic and translocation capacity when compared with other treatments (Anon., 2003) (Table 3). Such tea bushes allocate sufficient carbohydrates for growing buds and small shoots than those of stressed tea bushes. The higher severity of harvesting (HSH) and removal of *arimbu* shoots (RAS) exert a considerable physiological stress to the tea bushes (Wijeratne, 2012). They also consume much of the carbohydrates for subsequent growth of emerging shoots continuously (Wettasinghe *et al.*, 1981; Visser, 1960). Similarly, the combined simulations and motorized mechanical harvesting also remove considerable amount of *arimbu* shoots resulting in greater physiological stress and decrease total shoot density (Wijeratne, 2003; Madamombe, 2013). Under these harvesting methods, most of the *arimbu* shoots are not allowed to produce mature leaves (they are removed prematurely) that are later added to the maintenance foliage contributing to growth of the bush as a “source” of carbohydrates. The removal of maintenance foliage alone however, has exerted an intermediate level of stress that shoot density of these plots was not as low as RAS and HSH.

Table 3. Total shoot density (count bush^{-1}) and average shoot weight (g shoot^{-1})

Treatments	**Total shoot density**	**Average shoot weight**
Manual	215^{a}	0.83^{a}
MMH	161^{c}	0.63^{c}
RMF	190^{b}	0.75^{b}
RAS	147^{c}	0.59^{c}
HSH	165^{c}	0.73^{b}
CS	156^{c}	0.64^{c}

Means with the same letter are not significantly different at *p=0.05*. Each mean is derived from 4 replicate plots. MMH = Motorized Mechanical Harvesting, RMF = Removal of Maintenance Foliage, RAS = Removal of Arimbu Shoots, HSH = Higher Severity of Harvesting and CS = Combined Simulations

The average shoot weight of tea bushes where *arimbu* shoots were removed (RAS) and combined simulations (CS) were comparable to those harvested by motorized machine (MMH) and were significantly (p<0.0001) lower than the other treatments (Table 3). Although, removal of maintenance foliage (RMF) and higher severity of harvesting (HSH) exhibited higher shoot weight than MMH, they were still lower than that of manual harvesting. The highest reduction in the average shoot weight (29%) was observed with RAS, followed by MMH (24%) and CS (23%). The HSH and RMF however, reported only 12% and 10% reductions in shoot weight respectively, compared to manual harvesting. *Arimbu* shoots and growing buds act as strong sinks (Manivel and Hussain, 1982; Barman and Saikia 2005) and their removal affects the Sink:Source balance of the tea bush (Wijeratne, 2003) subsequently influencing photosynthesis. Since, RAS, CS and MMH treatments remove *arimbu* shoots, their inclusion in the method of harvest subsequently results in low shoot weights. Both HSH and RMF cause stress to the tea bush which also reduces shoot weight (Visser, 1960; Wettasinghe *et al.*, 1981) but not as much as RAS. These findings reveal evidence that RAS affects more than RMF and HSH on tea bush physiology.

Formation of *banji* shoots was significantly (p=0.0003) low in manual harvesting and with removal of maintenance foliage (RMF) compared to all other treatments, due to less stress to the tea bushes (Table 4). The higher severity of harvesting (HSH), removal of *arimbu* shoots (RAS) and combined simulations (CS) were comparable with machine harvesting (MMH) in regenerating *banjies*. Higher physiological stress exerted by those treatments has stimulated dormancy of tea bushes and caused subsequent yield reduction. Moreover, *banji* shoots are 10-18% less in weight than active shoots and take longer time (2-3 months) to get activated and re-grow (Wijeratne, 2003). Hence, *banji* formation (*banjiness*) affects both average shoot weight and shoot density (yield components of the tea crop).

The removal of *arimbu* shoots (RAS) and combined simulations (CS) reduced girthing of branches significantly (p=0.0197) affecting frame development, results of which is comparable to that of machine harvesting (MMH) (Table 4). The highest girthing was reported by manual harvesting. Girthing gives an indication on the growth of vascular bundles and poor growth of vascular bundles affects translocation of water, nutrients and assimilates between root and canopy (De Costa, 2004). These results indicate that RAS and MMH were equally responsible for weakening the translocation capacity and consequently affecting productivity and health of tea bushes. However, girthing of branches under RMF and HSH treatments were comparable with that of manual harvesting.

Table 4. Formation of *banji* shoots and gain in the girth of secondary branches

Treatments	% *Banji*	Girth gain (mm)
Manual	18.86^{b}	1.52^{a}
MMH	32.03^{a}	0.33^{c}
RMF	23.66^{b}	1.26^{ab}
RAS	32.75^{a}	0.51^{bc}
HSH	31.68^{a}	1.24^{ab}
CS	31.81^{a}	0.51^{c}

Means with the same letter are not significantly different at p=0.05. Each mean is derived from 4 replicate plots. Percentage *banji* based on the shoot counts compared to total shoot density. Gain in girth is the difference in branch diameter at the beginning and after one year. MMH = Motorized Mechanical Harvesting, RMF = Removal of Maintenance Foliage, RAS = Removal of Arimbu Shoots, HSH = Higher Severity of Harvesting and CS = Combined Simulations

In the early stage (6 months), manual harvesting and removal of maintenance foliage (RMF) did not show any significant (p<0.0001) variation in root starch contents (Figure 1a). However, all other treatments reported low root starch reserves six months after the imposition of treatments. Further after one-year, lower root starch contents were reported with higher severity of harvesting (HSH), removal of *arimbus* (RAS), combined simulations (CS) and machine harvesting (MMH), in comparison with manual harvesting. The RMF, however, showed an intermediate level of depleting root starch reserves. According to Figure 1a, there is a reduction in root starch contents with time even in the manual harvesting as reported before by Pathiranage *et al.*, (2016). Frequent heavy removal of *arimbu* shoots (by RAS, CS and MMH) and higher severity of harvesting (HSH) force the tea bush to consume a lot of carbohydrates for the re-growth of buds without any contribution to the source by way of adding mature leaves. This impaired Sink: Source balance together with poor translocation capacity can aggravate this situation. Root starch reserves deplete heavily under such conditions. However, removal of maintenance foliage alone contributed less in depleting root starch reserves than other two mechanical simulation treatments.

The removal of maintenance foliage (RMF), removal of *arimbus* (RAS) and higher severity of harvesting (HSH) individually did not affect leaf thickness (Specific Leaf Weight, SLW) significantly (p=0.0151) and reported comparable values as manual harvesting for a period of about 6 months (Figure 1b). However, one year after imposition of treatments, significantly (p=0.005) lower SLWs were found with combined simulation (CS) and machine harvesting (MMH) treatments in comparison with individual contributions of RMF, HSH and RAS and manual harvesting treatments. The leaf thickness is a good measure of available chlorophyll content in the leaf (Bhardwaj and Singh, 1988; Kunio *et al.*, 1995) which has a linear relationship with photosynthesis (Tao *et al.*, 1992). Therefore, it is clear that CS or MMH adversely affect the photosynthetic capacity of leaves and hence, carbohydrate production of the tea canopy leading to yield reduction and poor bush health.

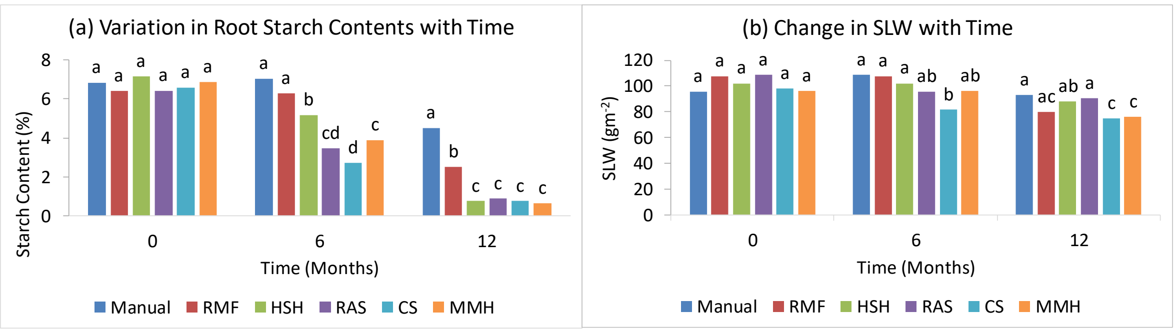

Figure.1. Effect(s) of different harvesting treatments on (a) root starch contents and the (b) Specific Leaf Weights (SLW). Bars with the same letter(s) do not differ significantly at p=0.05. MMH = Motorized Mechanical Harvesting, RMF = Removal of Maintenance Foliage, RAS = Removal of Arimbu Shoots, HSH = Higher Severity of Harvesting and CS = Combined Simulations

CONCLUSIONS

Continuous motorized mechanical harvesting reduces tea yield by means of three main impacts *viz.* removal of maintenance foliage, higher severity of harvesting and removal of *arimbu* shoots. The removal of *arimbu* shoots contributed to about 55% of the yield reduction followed by higher severity of harvesting (about 15%) and removal of maintenance foliage (about 12%). Removal of *arimbu* shoots directly disturb the Sink: Source relationship affecting photosynthesis and subsequently reducing the available carbohydrates for growth and maintenance of the bush. Less availability of carbohydrates results in weakening the frame development and translocation capacity. Short supply of carbohydrates and affected translocation of water, nutrients and assimilates between roots and canopy together deplete root starch reserves. Subsequently, low shoot density and dormancy of the tea bush reduce tea yield. However, contribution of the other two factors *i.e.* higher severity of harvesting and removal of maintenance foliage cannot be neglected since they are also yield determining factors in tea.

Since, it is very difficult to prevent removal of *arimbu* shoots with the presently available tea harvesting machinery in the market, the way out for arresting yield reduction will be minimizing the removal of maintenance foliage and avoid a deep cut into the plucking table (low severity). Avoiding several passes of the harvester on the same location of the plucking table will help decreasing the severity of harvesting of shoots and removal of maintenance foliage and *arimbu* shoots. Minimizing environmental stresses by proper shade management, adopting good agricultural practices, irrigation during unfavorable weather conditions and use machine only during cropping months will minimize yield losses and adverse impacts on bush health.

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