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Productivity Improvement of Smallholder Coffee Plantation to Prevent the Expansion of the Plantation into Protected Forest

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***Abstract*— Farmers expanded the smallholder plantation to the protected tropical rainforest area due to declining of coffee productivity by the old age of coffee trees and degraded soils in West Lampung, Sumatra Island of Indonesia. The research aimed to study the performance of rehabilitated Robusta coffee trees and citronella grass (*Andropogon nardus* L.) as a conservation crop to improve the smallholder coffee plantation productivity. The old Robusta coffee trees (more than 25 years old) were rehabilitated by side grafting. Scions for the grafting were superior clones such as *Sumber Asin* (SA) 237, *Besoekish Proefstation* (BP) 436, and 534. In the experiment, two scions were grafted to each of 600 local Robusta coffee trees. To know the effect of grafting, the coffee trees were observed using stratified random sampling with equal sample allocation. The strata were varying positions of land on the hill, i.e., peak, ridge, and bottom, and the other were the three clones. The citronella was planted along the contour line among the coffee trees, with a vertical interval (VI) was 1.25 m. On average, the two grafted branches of coffee trees could produce green beans 453 g. It was higher than the average yield of the farmers' coffee trees, i.e., 387 g tree^{-1}. The SA 237, however, was vulnerable to the attack of berry borer (*Hypothenemus hampei*). Besides, to control erosion, the citronella grass under 40 to 60% covered by coffee trees canopy, produced fresh leaves 10-ton ha^{-1}year^{-1} or essential oil as much as 87 L (essential oil content of leaves 0.87%), approximately. That was equivalent to $1,115 in a year. The citronella also improved the soil chemical properties, especially organic-C, P_2O_5, Ca^{2+}, Mg^{2+}, and Al^{3+}.**

***Keywords*—coffee tree rehabilitation; citronella grass; conservation crop; side grafting; smallholder plantation.**

I. INTRODUCTION

In West Lampung of Southern Sumatra Island, Indonesia, coffee farmers tend to expanse the Robusta coffee plantation to the area of the protected tropical rainforest, recognized as *Bukit Barisan Selatan National Park* (BBSNP). Around 89,224 hectares (28%) of the active agricultural area in that place was BBSNPs' area [1]**.** In 2008, the BBSNP Bureau estimates, 16,312 families had illegally occupied an area of 57,089 ha of BBSNP, mostly for coffee plantation [2]. The expansion of the farmers to the BBSNP is due to the productivity of farmers' coffee plantation out site the area declined [3].

In the highland, West Lampung, the farmers planted the Robusta coffee trees on hilly areas with a 25% slope or more, generally. The average green bean yield of farmers' Robusta coffee was below 1 ton ha^{-1}. Some obstacles in increasing coffee production were the old age of existing coffee trees and the degradation of soil due to erosion [3]. The old age of the existing coffee trees because the farmers intensively planted the trees in the 70s and 80s [4].

Robusta coffee is an easily propagated plant, among others, by a grafting technique [5], [6]. One of the factors determines the success of the grafting was the clones of the scion [6]–[8] It is recommended in the previous study that some clones of BP such as BP 234, BP 288, BP 436, and BP 534 and also clone of SA 237 as the scion of grafting for the rehabilitation of the old Robusta coffee trees on the acid soil with an altitude more than 400 m above sea level (ASL) [9]. The BP is a generation of 1 to 3 superior clones in Indonesia with parent trees originating from Congo [10]. Another superior clone was released, the SA 237 with the parent trees originating from West *Kendeng Lembu* garden, and primary and secondary testing carried out at *Sumber Asin* experimental Station in East Java Indonesia [9].

The grafting technique for the plant rehabilitation and likewise, a conservation crop planting could be applied to accelerate the smallholder Robusta coffee plantation productivity improvement [3]. As the conservation crop, citronella grass was recommended due to in addition to overcome the rapid degradation of soil by erosion [11], [12], it produces an essential oil with high economic value [13] to add farmer income [3].

The citronella was also functioned as phytoremediation of metal-polluted soil [14], while its essential oil contains geraniol, trans-citral, *cis*-citral, geranyl acetate, citronellal, and citronellol [15]. The citronellal and geraniol were the most important ones due to exhibiting insecticidal and repellent properties. Its pleasant odor was used for an ingredient in consumer products and fragrance industries [16]–[18]. The essential oil could also be processed into additives to increase the efficacy of premium fuel [19], [20]. This research aims to study the performance of rehabilitated Robusta coffee trees by grafting and citronella grass (*Andropogon nardus* L.) as the conservation crop to improve the smallholder coffee plantation productivity.

II. Materials and Method

A. The Experimental Site

The experimental site was in the Sumber Jaya sub-district as the one of *Robusta* coffee production center in the highland, West Lampung. The outermost of the smallholder coffee plantation in West Lampung District is directly adjacent to BBSNP. The experiment began in May 2014. A meeting with some members of the coffee farmer group organized by the local plantation counselor was the first activity of the experiment. The last observation was in August 2016 to collect some data on the growth and yield of grafting branches on local Robusta coffee trees.

The experimental site was on sloping land of 10 to 15% on the hill peak and 25 to 40% on the hill ridge. The area is about 800 m above sea level (ASL). The experimental field coordinate was on 5°00'21.1" S and 104°27'33.2" E, with the annual rainfall was 2,500 to 3,000 mm, and the average minimum and maximum air temperature were 21.5°C and 24.8°C, respectively. The soil is *Inceptisols* with *Humitropepts* and *Dystropepts* as a dominant soil in the great-group level [21]. The soil sample from the peak, the ridge, and the bottom of the hill to a depth of 0 to 20 cm were collected and analyzed to identify the chemical soil characteristics. The laboratory measurements of the chemical properties of the soil sample are in Table 1.

TABLE I
THE CHEMICAL SOIL CHARACTERISTICS OF THE EXPERIMENTAL FIELD IN THE HIGHLAND, WEST LAMPUNG

Soil Properties	Units	The laboratory Measurements of Chemical Sampled Soil Properties			
		Peak	Ridge	Bottom	Average
pH		4.28	4.50	4.57	4.45
Organic C.	%	1.95	1.99	1.77	1.90
N	%	0.11	0.13	0.17	0.14
P_2O_5	mg $100g^{-1}$	20.35	21.44	25.16	22.32
K_2O	mg $100g^{-1}$	21.39	20.04	22.12	21.18
Ca^{2+}	cmol(+) kg^{-1}	1.27	1.28	1.30	1.28
Mg^{2+}	cmol(+) kg^{-1}	0.69	0.75	0.71	0.72
K^{+}	cmol(+) kg^{-1}	0.56	0.71	0.77	0.68
Na^{+}	cmol(+) kg^{-1}	0.94	1.35	0.99	1.09
CEC	cmol(+) kg^{-1}	14.62	15.74	13.49	14.62
BS	%	23.67	25.98	27.95	25.87
Al^{3+}	cmol(+) kg^{-1}	3.45	3.81	3.27	3.51
Al saturation	%	57.79	58.17	54.05	56.67

Notes: CEC = Cation exchange capacity, BS = Base Saturation

B. Side Grafting on Local Robusta Coffee Trees

The side grafting on 600 local Robusta coffee trees, all older than 25 years, was by two scions of three superior Robusta coffee clones each, namely 1) SA 237, 2) BP 436 and 3) BP 534, in rainy season 2014, on an area of 0.5 ha. Two prospective plagiotropic branches of the local Robusta coffee trees were cut about 10 cm from the main stem and 2 cm longitudinal cut made on them, while the scions with 7 cm lengths made 2 cm sloping cut, then they were joined firmly with plastic polyethylene. Other branches of coffee trees were left to continue to produce. A specialist technician with two experienced farmers needed four days to complete the side grafting.

The scions for the side grafting were taken from *Cahaya Negeri* Experimental Station of The Industrial and Beverage Crops Research Institute in North Lampung in the morning of the days before grafted. The distance of the experimental site to the *Cahaya Negeri* Experimental Station is approximately 25 km.

In general, in the experimental field, the spacing of the local Robusta coffee trees was irregular, with the distance between them were 2.5 to 3 m. The grafting arrangement of three superior Robusta coffee clones on the local Robusta coffee trees, however, was by an approach of 1:1:1 (Fig. 1) because the Robusta coffee tree is a cross-pollination plant. To support the growth of grafting, each grafted tree was supported by NPK fertilizer as much as 250 g $tree^{-1}$. The application of fertilizer was 50% at the beginning and 50% at the end of the rainy season.

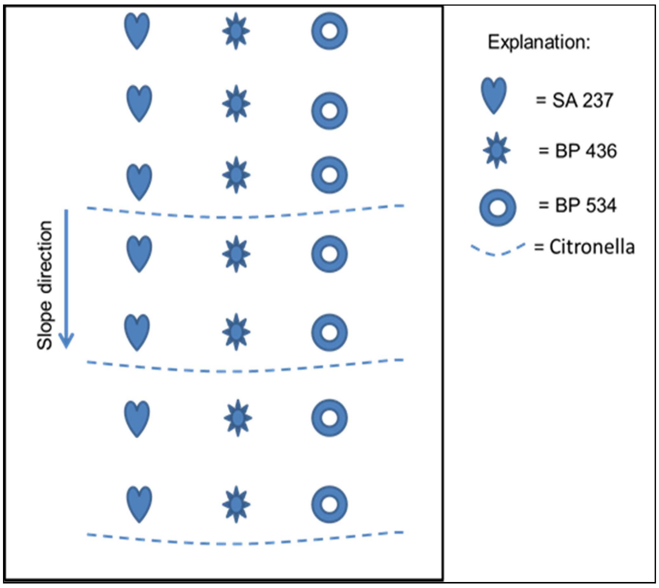

Fig. 1. The arrangement of the superior Robusta coffee clones grafting on the local Robusta coffee trees

C. Planting Citronella as a Conservation Crop

Planting of the citronella as the conservation crop along the contour line, using rhizome, was in the rainy season in October 2014. The planting distance between clumps of citronella in the contour line was 75 cm, with the vertical interval was 1.25 m. Fertilizer for each clump of citronella was 20 g urea, given a week after planting and at the end of the rainy season.

D. Observation of Side Grafting Growth Performance

Stratified random sampling was used in the observation of side grafting performance with equal sample allocation. The strata were determined by the varying positions of land on the slope, i.e., the peak, the ridge, and the bottom, and the other were the three clones used. The study used Slovins' formula to determine the sample size; n = N/(1+Ne2) with n as the sample size, N is the population size (600 trees), and e is the margin of error (10%). The formula generated 86 samples and 29 samples for each stratum.

The observation of the side grafting performance was at 20 months after grafting. It observed the branch length, the productive branches number, the bunch number in the branch, the berry number in the bunch, the green bean yield, and the berry percentages attacked by the borer ((*Hypothenemus hampei*). Identifying the borer attack was through recognizing the small holes around the coffee berries disc. The harvesting and processing of the berries were manual.

F-test was used to analyze data of the observations, and for the significant difference means the analysis was continued by a post hoc test of Tukey's HSD (Honestly Significant Difference) test at 5% significant level.

E. Performance of the Citronella Growth

An observation of the citronella growth began in 7 months after planting and then at every three months. The citronella performance observation, especially in producing a fresh leaves biomass, was onto the citronella growing on an area that less than 10 % and 40 to 60 % covered by Robusta coffee trees canopy. The citronella performance observation was onto the growing citronella on the area that less than 10 % and 40 to 60 % covered by Robusta coffee trees canopy. The reason for the site selection was the performance of the citronella growth was different in the area with a different density of Robusta coffee trees**.** Calculating the percentages of Robusta coffee trees covering the citronella (c) used the formula $c = 0.25d^2$, by d was the diameter of the average projection of the canopy of local Robusta coffee trees. The percentage of a canopy covering the planting area (C) = (c / total sample plots area) x 100 [22]. The citronella leaves were cut at 5 cm from the base of the leaves (ground) for seven months years old and every three months thereafter.

F. The Essential Oil, Citronellal, and Geraniol of the Citronella and Chemical Soil Properties under the Citronella Growth

To measure the content of essential oils in fresh citronella leaves, as much as 15 kg of fresh leaves sample was extracted using the steam distillation method, in Natar Experimental Station of Lampung Assessment Institute for Agricultural Technology. During the sampling, the fresh leaves of the citronella were immediately weighed, then put into some polyethylene plastics and carried to the Natar Experimental Station. The oil of extraction result was then kept in the bottle and taken to Laboratory of Indonesian Spice and Medicinal Crops Research Institute in Bogor to analyze the citronellal and the geraniol content by Gas Chromatography-Mass Spectrometry method.

As a conservation crop, the effect of the citronella growth on the soil properties was also studied. For that purpose, it was compositely sampled the soil at 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm from citronella clumps until the depth of 0 to 20 cm, both on the peak, the ridge, and the bottom of the hill. The soil sampling was done a year after the citronella planting. The chemical soil properties studied were a soil organic carbon (SOC) (method of Walkley and Black), P_2O_5 and K_2O (method of 25% HCl extraction), an exchangeable aluminum (Al^{3+}) and exchangeable cations (Ca^{2+}, Mg^{2+}, and K^+) (method of 1 M KCl extraction).

III. Results and Discussion

A. The Growth of Grafting

A result of the statistical analysis found that only the means difference between the variance of the three clones was significant, especially the means of branch length and the percentage of berries attacked by the borer (*Hypothenemus hampei)*. The branch of SA 237 clone on the local Robusta coffee trees was longer than BP 436 and BP 534 (Table 2). However, the green beans of SA 237 were attacked by the berry borer more than the clones of BP 436 and BP 534. It attacked the berries of SA 237 up to 20.3% (Table 3). The coffee berry borer was the most troublesome pest in the Highland West Lampung [3].

TABLE II
The Vegetative Growth of The Branch of Superior Clones Grafting on The Local Robusta Coffee Cultivar

The Clones	The longest productive branch (cm)	The number of productive branches for each grafting
SA 237	117.08 a	6.40
BP 436	107.45 ab	5.80
BP 534	96.03 bc	6.07
Average	106.85	6.09
SD	24.83	2.59

Values followed by the same letter are not significantly different (at $P < 0.05$) according to Tukey's HSD

The green beans yield of the two grafting branches of the three superior clones were not significantly different, which means the three clones applied had almost similar potential to rehabilitate the old Robusta coffee trees. The three superior Robusta coffee clones were the plants that were suitable for the polyclonal planting system and the rehabilitation of Robusta coffee trees, especially on the wet climate area, the acid soil and the altitude were more than 400 m ASL [9]. Nevertheless, they have different characteristics, particularly the SA 237 clone was relatively robust and having a long segment of branches and long branches, while the BP 436 and BP 534 branches were typically slender and bend.

The green beans yield of the two grafting branches on each local Robusta coffee tree was 453 g, on average (Table 3). It indicated that the grafting of superior clones had the potential for improvement of the local Robusta coffee productivity. That was due to the coffee farmers' around the experimental field produced the green beans approximately 90 to 600 g $tree^{-1}$ in 2013, or on average was 387.5 g $tree^{-1}$ (Table 4).

TABLE III
THE GENERATIVE GROWTH OF THE THREE SUPERIOR CLONES GRAFTING ON THE LOCAL ROBUSTA COFFEE TREE AND PERCENTAGES OF COFFEE BERRY BORER (HYPOTHENEMUS HAMPEI) ATTACK ON THE BERRIES OF EACH CLONE

The Clones	The number of bunches per brunch	The number of berries per bunch	The green beans yield of two grafted brunches (g)	The percentages of coffee berry borer attack (%)
SA 237	8.27	20.90	452.29	20.33 a
BP 436	8.67	23.33	476.99	14.83 b
BP 534	7.80	20.43	428.63	18.67 ab
Average	8.25	21.55	452.64	17.94
SD	2.18	7.48	190.40	7.82

Values followed by the same letter are not significantly different (at $P < 0.05$) according to Tukey's HSD

TABLE IV
THE GREEN BEANS YIELD OF SOME FARMERS COFFEE TREES AROUND THE EXPERIMENTAL FIELD IN 2013

No.	Farmers	Number of Productive coffee trees	Total green beans yield (kg)	Green beans yield per tree (g)
1	Kanak	2500	900	360
2	Nursalim	400	200	500
3	Sri Muning	500	300	600
4	Harni	1100	100	90
Average				387.5

B. Performance of the citronella

The result of leaves cut of citronella grass found that the fresh leaves weight of citronella biomass on the area covered by coffee trees canopy 10% or less was four times higher than covered by 40 to 60 % of coffee trees canopy (Fig. 2).

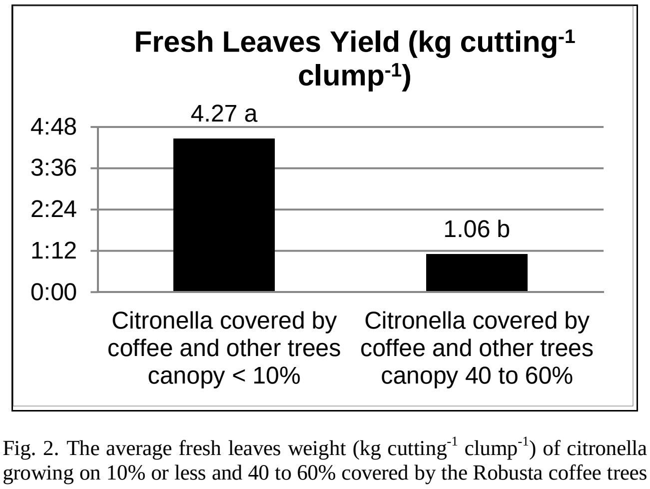

Fig. 2. The average fresh leaves weight (kg $cutting^{-1}$ $clump^{-1}$) of citronella growing on 10% or less and 40 to 60% covered by the Robusta coffee trees canopy in the highland, West Lampung.

The citronella was a grass species with wide adaptability and ability to flourish in abandoned hill slopes, alkaline soils, and various wastelands [23]. Pareek & Gupta in [24] reported the citronella did not tolerate the shade and under diffused light. In contrast, as an intercropping in the regularly pruned cinnamon plantation for bark extraction, the essential oil of the citronella was profitable. By the length of contour line in a hectare was 2,000 m approximately, the citronella leaves cut after seven months old and every three months. After that, it produces the fresh leaves biomass as much as 10-ton ha^{-1} $year^{-1}$, especially in the area covered by the canopy of coffee trees 40 to 60%.

C. The essential oil, citronellal, and geraniol of citronella

The content of the essential oil of fresh citronella leaves was 0.87 %. Then extraction results found its essential oil contained citronellal of 17.74% and geraniol of 35.54% (Table 5). The environment affected the essential oil composition of the citronella. The essential oil and its major components like citronellal and geraniol were much better under the moderate air temperature (20 - 30ºC), as the average air temperature in the highlands of West Lampung was 21-25 ºC [25].

As mentioned above, the citronella as the conservation crop could produce the fresh leaves biomass 10-ton ha^{-1} $year^{-1}$. It means the farmers of the smallholder plantation had a chance to get an additional income from 87 kg of the essential oil (0.87% of 10 ton). By citronella oil price of IDR 180,000 kg^{-1} in 2016, the farmers had a chance to get an additional gross income as much as IDR 15,660,000 $year^{-1}$ or equivalent to $1,115 $year^{-1}$. The calculation had not yet considered a cost for the distillation process in the field.

TABLE V
THE ESSENTIAL OIL OF CITRONELLA AND ITS CITRONELLAL AND GERANIOL CONTENT, PLANTED IN THE HIGHLAND WEST LAMPUNG INDONESIA

Fresh Citronella Leaves	Content (%)
Essential oil content	0.87
Citronellal in the essential oil	17.74
Geraniol in the essential oil	35.54

D. Chemical soil properties under the citronella growth

Laboratory measurements of chemical soil samples properties showed that the organic C in the depth of 0 to 20 cm was higher at 0 to 10 cm (2.12%) than at 10 to 20 cm and 20 to 30 cm from citronella clumps. The extractable P_2O_5 at the same place was equally, i.e., tended to be better at 0 to 10 cm (22.35 mg 100 g^{-1}) than at 10 to 20 cm and 20 to 30 cm from citronella clumps, as well as the exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}). Yet the content of exchangeable aluminum (Al^{3+}) at 0 to 10 cm tended to be lower than at 10 to 20 cm and 20 to 30 cm from citronella clumps (Fig. 3).

The citronella could improve organic C in the soil at 0-10 cm from citronella clumps due to the roots of citronella exude some sources of soil organic C, such as organic acids, sugars, and amino acids [26]–[28]. The organic acids, especially the low molecular weight organic acids, chelated Al, and forming a non-toxic complex organic-Al compound [29]–[31]. It caused the exchangeable Al closed to citronella clumps to decrease [32]. The organic acids also stimulate the rhizosphere processes and dissolve unavailable P and Ca to be available in the soil [33].

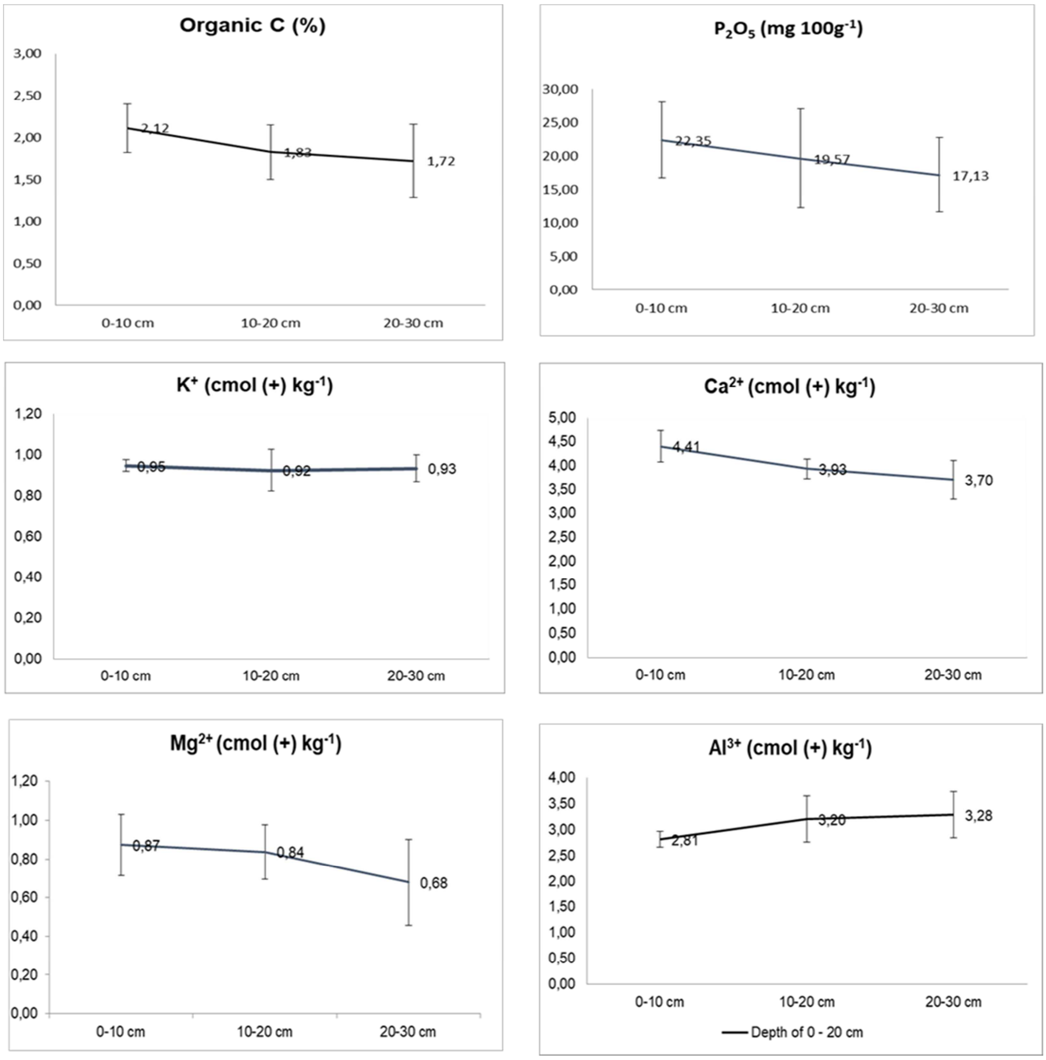

Fig. 3. Some chemical soil properties in the depth of 0-20 cm at the distance of 0 to 10 cm, 10 to 20 cm and 20 to 30 cm from the citronella clump in the highland, West Lampung.

IV. CONCLUSION

The rehabilitated Robusta coffee trees by side grafting and the citronella grass as the conservation crop could potentially improve smallholder Robusta coffee plantation productivity in the highland, West Lampung Indonesia. The side grafting of two scions of superior clones (SA 237, BP 436, and BP 534) on a local Robusta coffee tree could produce the green beans yield of 453 g on average. It was higher than the average green beans yield (387 g tree^{-1}) of the local Robusta coffee trees around the experimental area. The citronella covered by the canopy of the Robusta coffee trees 40 to 60% could produce fresh leaves as much as 10 ton ha^{-1}year^{-1} (1.06 kg clump^{-1}cutting^{-1}). By 0.87% essential oil content, the farmers would get an additional income as much as IDR 15,660,000 or equivalent to $1,115 in a year. Besides, the citronella also improves some chemical soil properties such as organic carbon, phosphorus, Ca^{2+}, Mg^{2+}, as well as reducing Al^{3+}.

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