Org. Agr.
https://doi.org/10.1007/s13165-018-0224-z

Cacao plantations on Sulawesi Island, Indonesia: I—an agro-ecological analysis of conventional and organic farms

André Freire Cruz · I Nengah Suwastika · Hayao Sasaki · Tomoharu Uchiyama · Nurul Aisyah Pakawaru · Wahyuningsih Wijayanti · Muslimin · Zainuddin Basri · Yoko Ishizaki · Takashi Shiina

Received: 26 April 2018 / Accepted: 11 July 2018

Abstract The cacao plantation largely contributes to the Indonesian agricultural economy, and the systems with less environment impact have become fundamental for the local farmers. The current research made a general agro-ecological evaluation of six cacao farms in Sulawesi-Indonesia cultivated under conventional systems and organic management, here referred to as environmental friendly systems (EFS). Ten agro-ecological parameters, the number of fruits per area, the rate of infection (RI), number of seeds per fruit, and seed weight per fruit were evaluated. Furthermore, plant mineral nutrition was also analyzed, including the estimation of diagnosis recommendation integrated systems. The overall data indicated that RI in the conventional systems was lower than that in the EFS. The density of dead plant materials showed negative correlations with the area of weeds and density of weeds. The density of dead plant materials, concentrations of Mg and Fe showed a positive correlation with productivity. In addition, Fe showed negative correlations with weed area and density. The nutrient balance index also showed that in Parigi and Palolo areas, the plants were well stabled in terms of mineral nutrition. These results suggest that some agro-ecological parameters can function as cacao production indicators, especially the biomass and dead leaves together with plant mineral nutrition (Mg and Fe).

Keywords Agro-ecology · Diagnosis recommendation integrated systems · Plant nutrition · Yield · Weeds

Introduction

Cacao (*Theobroma cacao* L.) is a crop grown largely by smallholders in the lowland tropics. The cacao industry has a strong impact on the global economy and social development in the region. Indonesia is actually the

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s13165-018-0224-z) contains supplementary material, which is available to authorized users.

A. F. Cruz (✉) · Y. Ishizaki · T. Shiina
Graduate School of Life and Environmental Sciences, Kyoto Prefectural University, Kyoto, Japan
e-mail: andre@kpu.ac.jp

I. N. Suwastika · N. A. Pakawaru
Department of Biology, Faculty of Sciences, Tadulako University, Palu, Indonesia

H. Sasaki · T. Uchiyama
Faculty of Agriculture and Life Sciences, Kyoto Prefectural University, Kyoto, Japan

W. Wijayanti · Muslimin
Faculty of Forestry, Tadulako University, Palu, Indonesia

Z. Basri
Faculty of Agriculture, Tadulako University, Palu, Indonesia

Published online: 27 July 2018

third largest producer of cacao beans worldwide (Schwendenmann et al. 2010), with Sulawesi showing the most significant increase in cacao production in recent decades, now accounting for 75% of the national production. Cacao is now the main source of income for farming households (Indonesia Investments 2015).

Environmental friendly systems (EFSs), which sometimes include the organic agriculture, have been studied and reported worldwide in terms of their ecological benefits, which improves soil microbial activity and diversity. Many researchers have mentioned the importance of increases in agricultural production, minimizing the environment and human health negative impacts. Within such challenge, the organic farming, which aims to produce food with less negative effect on ecosystems, is often proposed. However, many researchers and farmers had criticized this system by arguing the lower yields and product quality would therefore lead to lower incomes than conventional farmers would. A meta-analysis conducted worldwide suggested that in a long term, the organic rotation does not differ in their yield ratio as compared to conventional systems (Seufert et al. 2012). In Bolivia, at the Alto Beni region, the cacao organic farms reached higher tree and crop diversity, yields, and incomes, in addition to more social connectedness (Jacobi et al. 2015). Moreover, in a short term of a worldwide survey showed that cocoa yields were 47% lower in the organic compared to the conventional monoculture, and in a long term, the cumulative yields of all products harvested in organic systems overtook conventional ones (Schneider et al. 2017).

Thus, the evaluation of both conventional and organic systems in cacao plantation would be useful background for local farmers, as they could even decide which system is more viable in a long-term production.

One of the characteristic features of such system is the presence of terrestrial weeds, whose species richness has increased sharply and rapidly in response to changes in cacao management in Central Sulawesi, Indonesia (Cicuzza et al. 2012). Moreover, these weed species' biomasses were all significantly higher in the infrequently weeded plots than in the frequently weeded ones. However, their response to fertilizers was very low, and the species showed no clear patterns relative to their ecology or biogeography. It is worthy to use some agricultural indicators to evaluate the current situation of the cocoa plantation. Some of them are very useful such as weed control, fertilization, weeds presence, fruit size, and plant nutrition. The weeds sometimes are good indicators, and their interactions with other organisms might affect the agro-ecosystem functions (Petit et al. 2011). Among the edaphic factor, the soil potassium, organic matter, and sand amount strongly influenced the weeds in maize plantations (Ahmad et al. 2016).

Plant mineral contents play an important role on plant growth and productivity (Marschner 2011) with special focus to the chemical composition of the cacao beans as the basis for quality definition (de Araujo et al. 2017). One significant example is that although the soil nutrient status is sufficient, total P availability and stagnant soil water conditions limit yields (Juhrbandt et al. 2010). Moreover, the element balance within the plants, estimated by the Diagnosis Recommendation Integrated System (DRIS), could determine their mineral nutrition status (Wadt 2014; de Matos et al. 2018). Some data could be used as ecological indicators, which provides the idea on the local farm management situation and factors that might affect the productivity. The overall impact of the effects of agricultural management including the productivity, fertilizer, pesticide using, in cacao plantation located in Central Sulawesi is still unknown, and a general agro-ecological evaluation of these diverse places would be appropriate. Thus, this study focused to understand the interrelationships between productivity, agricultural management, and plant health. To this end, agro-ecological parameters represented by fruit size, weed presence, plant nutrition, and soil fertility were analyzed. In parallel, interviews with Indonesian farmers were performed to evaluate how their management could affect production.

Materials and methods

Experimental design and interviews

Samples and interviews were carried out on six cacao farms located in Palolo, Kulawi, Sarjo, Sidondo, Parigi, and Poso in Central Sulawesi, Indonesia (Suppl. Fig. 1). Two kinds of systems were visited at each farm site (conventional and organic). The characterization of the sampled areas (Suppl. Table 1) and the soils (in preparation) is described. The organic plots here referred to the environmentally friendly system (EFS), which maximizes the use of organic fertilization and avoids as many chemical pesticides and herbicides as possible.

However, occasionally, the farmers still applied some chemical-based products (fungicides and insecticides) under certain extreme conditions, such as serious pathogen and pest attack. Moreover, there is no certification agency in that area which qualifies these farmers are organic producers; thus, in this research, the EFS is more suitable to define such system. The experimental design was composed of 6 locations, 2 systems, and 4 samples totalizing 48 experimental units. Sampling was performed in August 2015 and at each sampling site (Suppl. Fig. 1). We interviewed local farmers about (1) yields per hectare, (2) methods to maintain soil fertility, (3) methods to control pests and disease, (4) frequency of weed control (freqW), (5) frequency of pruning (freqP), and (6) the grafted clones used. The leaves were also taken from the middle of the canopy at the second branch, and then they were washed, drought at 60 °C for 3 days, and finally ground to be submitted to plant mineral nutrition analysis. The ground material was applied to sulfuric and nitro-perchloric digestions before the mineral analysis.

Plant mineral nutrition and statistical analysis

The total N in plant leaves was estimated using the Kjeldahl method after sulfuric digestion (Bellomonte et al. 1987). Total P levels in extracts obtained by nitro-perchloric digestion were determined using the spectrophotometric vanadium phosphomolybdate method. The same sample extract was used for atomic absorption spectrophotometer (AAS) analysis of levels of K, Mg, Ca, Zn, Mn, Cu, Fe, and B. The di-acid (HNO_3-$HClO_4$) digestion method followed by turbidimetric methods was used for S analysis (Isaac and Johnson 1985). All analyses were performed by Mycellium Co., Barretos, Brazil.

The Diagnosis Recommendation Integrated System (DRIS) was used to quantify all nutrients and then calculate the Nutrient Balance Index (NBI) (Wadt et al. 2007; Wadt 2014). SPSS 10.0 was used for statistical analysis to calculate standard errors of means and Pearson's correlation coefficients.

Agro-ecological research

We sampled three rectangular areas (1 × 6 m) in each location (Fig. 1). After measuring the rectangles, we quantified healthy fruits, infected fruits, and sampled mature fruits within this area. Then, the number of fruits

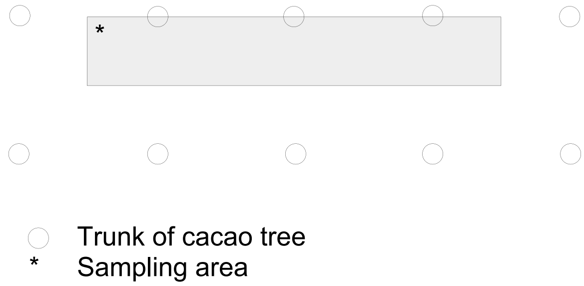


Fig. 1 Model of sampling area

per area (NF) and the rate of infection (RI) were calculated. Also, the trunk diameter of three cacao trees (DT) at a height of 50 cm from the ground was measured. By horizontally crossing the area, we then counted the total number of steps and the number of those steps that were on weeds and used this to calculate the area of weeds (AW, %). Next, a sub-area of 40 × 40 cm was taken to measure the density of weeds (DW) and dead plant materials (DDPM). Finally, we measured the lengths and diameters of fruits (LF and DF, respectively) and quantified the number (NSF) and weight (WSF) of seeds per fruit.

Results

Interview

According to the interviews as shown by the fluctuation of yield and fertilizer using amount, the yield of EFS and conventional tended to increase and decrease over time respectively; however, the amount of fertilizer using increased in both systems. Except in Poso areas where the amount of fertilizer using maintained constant in conventional areas and decreased in EFS ones. Kulawi, Palolo, and Sidondo managed with EFS used solid and liquid fertilizers composed of a mixing with animal manure and plant residues (unpublished data). The highest yield was from the organic system in Parigi. Some cacao plantations are based on the EFS, and the effect of the amount of fertilizer was not different compared to that in the conventional ones. In Sarjo, freqW and yield were higher for the EFS, whereas in Palolo, there was an increasing of pruning frequency and higher yield in the conventional system. The highest variety of clones was found in the EFS in Parigi. As stated in the interview data, there are several clones grafted in each cacao farm; recently, due to diseases and low production problems, they tend to substitute the old varieties by new clones. The S1 and S2 were the most frequent in the sampled areas. Taken together, these data revealed the structure of cacao plantation in Indonesia (Table 1).

Agro-ecological research

In addition, the conventional system only in Sidondo area showed better results for NF, but not for RI; in contrast, the organic system in Sidondo had the lowest RI. Generally, the NF and RI were higher and lower organic areas respectively. The highest NSF was from the conventional system in Parigi, which also had the second highest MSF. Parigi showed the highest MSF in the organic system. Interestingly, every value of RI in conventional systems was higher than values in EFS. Moreover, RI values on the seacoast were usually higher than RI values inland, suggesting that other factors may be influencing this parameter (Table 2).

Plant mineral nutrition

The highest level of N was found in the organic system from Sarjo, which also showed high levels of P. The highest levels of P and of K overall were found in the organic system from Poso. Calcium levels were highest in the conventional system in Sidondo (Table 3). The overall results of mineral nutrition showed that the N and Zn had higher values in Seacoast areas as compared in Inland. The N, P, Ca, Zn, and Fe suffered effects of location, where the concentration of Ca and Zn were higher in Palolo and Parigi, respectively. Kulawi had the lowest Fe, but in terms of systems, there was no effect in general. It was observed mostly in each place independently (Table 3).

Table 4(a) shows the indices calculated for DRIS, whose value indicates the balance of each nutrient in the leaves of cacao. A positive value indicates a level of the nutrients in excess of the recommended value, and a negative value indicates a deficiency of the nutrient. Overall, we found the highest DRIS indices were for Ca, which was the most deficient nutrient, and P, which was most in excess, both in the conventional system from Kulawi. At seacoast areas, conventional system, the B was deficient, whereas the similar element only was in excess in Sidondo (Table 4(b)). Finally, the NBI was calculated from DRIS indices, which indicated a higher value in the EFS in four areas (Kulawi, Palolo, Poso, and Sarjo); however, only in Sidondo was such value lower in EFS (Fig. 2).

The correlations between agro-ecological parameters and mineral levels in leaves of cacao were calculated (Table 5). Nine pairs (N-DDPM, P-AW, K-LF, Ca-AW, Mg-DDPM, Zn-AW, Mn-LF, Cu-DW, and B-DW) showed correlation at the 0.05 significance level, and five pairs (Fe-NF, Fe-MSF, Fe-AW, Fe-DW, and Fe-DDPM) showed correlations at the 0.01 significance level. The RI means in EFS were also significantly different from those in conventional systems at the 0.01 confidence level. Although RI showed negative correlations with N in soil and FreqW, the means of neither of these parameters in EFS differed significantly from those in conventional systems.

Discussion

The overall survey indicated that the EFS could in certain mode function well, and in the long term, it could be considered sustainable agriculture. It means that the alternative managements with less chemical fertilizers and pesticides could maintain the productivity. Intriguingly, the amount of chemical product used in the EFS was lower than that in conventional ones. This suggests that the net profit from using the same amount of fertilizers is greater in organic cultivation so that in other cases, this system could be more economically profitable despite its lower yield (Nemes 2009). Additionally, a deep survey in Bolivia has shown that cacao yields were higher in monocultures, but the revenues derived from sustainable management areas including agroforestry economically overcompensated such difference, leading to conclude that cacao agroforestry systems have a higher return on labor (Armengot et al. 2016).

Contrary to our expectations, we did not find significant differences in nutrient concentrations in leaves in either the EFS or conventional ones. It is reasonable to consider that while the amount of fertilizer affected productivity, other factors such as microbes on the surface of fruits, insect species, cacao house covering material, and soil health could also have affected productivity. Despite the benefits of both chemical and organic fertilizers, farmers need to consider the environmental risk of their excessive application, particularly with regard to N cycling in the soil (Kemmitt et al. 2006; Saito et al. 2008; Xue et al. 2013). The NBI, an indicator of the nutritional status of the plants (Wadt et al. 1999, 2007),

Table 1 Result of interview on Sulawesi Island, Indonesia

Place	System	Location	Yield ($t\ ha^{-1}$)	Yield fluctuation last 5 years	Used fertilizer	Amount ($kg\ ha^{-1}$)	Fertilizer using fluctuation last 5 years	Pest and disease control	Weed control			Freq. of pruning per year	Used clones
									$L\ ha^{-1}$	Times per year	Labor per ha		
Inland	Conventional	Kulawi	0.5	Decreasing	Urea NPK (15-15-15)	300,300	Increasing	Pesticide (Nordox)	15	2	3	3	2 S2, Local
		Palolo	0.5	Decreasing	urea	500	Increasing	Plastic cover		3	1	5	3 S2, hybrid
					Ponska	500		Pruning					
		Sidondo	3	Decreasing	urea	1000	Increasing	Pesticide (Dursband)	7	12	1	2	7 Local, hybrid, S1, S2
	EFS	Kulawi	1.2	Increasing	Solid fertilizer	800	Increasing	Cleaning		3	4	3	4 S1, S2
					Liquid fertilizer	25 L							
		Palolo	0.6	Increasing	Liquid fertilizer Solid fertilizer	7 L	Increasing	Plastic cover Prunning		3	8	3	2 S2
		Sidondo	2	Increasing	Liquid fertilizer, solid fertilizer	5000, 1000	Increasing	Prunning Resisting clone		2.4	1	2	5 S2
Seacoast	Conventional	Parigi	0.8	Decreasing	Urea, Ponska NPK (15-15-15)	600, 600,600	Increasing	Pesticides	15	4	4	0	2 Local, hybrid
		Poso	1	Increasing	urea	500	Constant	Pruning		2	3	3	3 S1, S2, 045
		Sarjo	0.9	Decreasing	Urea, Ponska NPK (15-15-15)	500, 500, 500	Increasing	Pesticide (Alika)	2	6	7	3	7 hybrid, Local, S1 ICCRI1, Medan,
	EFS	Parigi	1.5	Increasing	Compost	2000	Increasing	Prunning		6	5	2	3 Panter, 045
		Poso	0.7	Increasing	Compost	4000	Decreasing	Prunning, cleaning		3	4	2	4 S2, 045
		Sarjo	3	Increasing	Compost, solid fertilizer	3000, 3000	Increasing	Prunning		42	5	3	5 S1, S2

EFS environmental friendly system

Table 2 Agro-Ecological parameters on Sulawesi Island, Indonesia

Place	System	Location	NF	RI (%)	NSF	WSF (g)	DT (cm)	LF (cm)	DF (cm)	AW (m^2)	DW ($g\ m^{-2}$)	DDPM ($g\ m^{-2}$)
Inland	Conv.	Kulawi	0.84(0.16)[a]	0.34(0.02)	41.75(1.65)	97.5(3.3)	12.6(1.26)	16.7(0.32)	6.95(0.1)	0.46(0.08)	159.38(7.86)	278.13(18.13)
		Palolo	3.26(0.79)	0.41(0.04)	30.75(4.39)	90(16.18)	12.75(0.72)	16.43(0.93)	8.28(0.29)	0.32(0.13)	23.44(10.94)	226.56(25.69)
		Sidondo	7.11(2.25)	0.58(0.1)	38.25(1.93)	41(11.83)	14.13(1.33)	16.1(0.49)	7.68(0.46)	0.14(0.04)	3.11(1.92)	532.81(75.32)
	EFS	Kulawi	1.33(0.48)	0.31(0.04)	35.25(2.87)	85(6.92)	11.23(0.66)	14.83(0.49)	7.3(0.36)	0.48(0.1)	182.81(12.07)	295.31(14.06)
		Palolo	5.33(1.6)	0.26(0.11)	28.75(4.96)	78.25(20.11)	9.43(2.58)	15.65(1.56)	7.73(0.34)	0.51(0.03)	37.5(21.04)	243.75(112.59)
		Sidondo	4.48(0.55)	0.1(0.05)	30.75(4.84)	81.5(15.23)	9.98(3.61)	15.98(0.64)	7.83(0.19)	0.21(0.02)	4.78(2.94)	481.25(45)
Seacoast	Conv.	Parigi	4.05(1.38)	0.46(0.08)	44.25(1.89)	114.75(18.06)	11.8(0.75)	16.1(0.88)	8.43(0.31)	0.7(0.09)	153.91(53.51)	284.38(31.92)
		Poso	3.11(0.8)	0.46(0.13)	23.75(6.18)	74.25(14.77)	12.55(1.41)	16.83(0.96)	7.53(0.42)	0.32(0.04)	48.44(28.68)	384.38(108.45)
		Sarjo	4.28(0.55)	0.35(0.08)	34(1.83)	62(11.34)	11.78(1.17)	16.7(1.08)	7(0.41)	0.09(0.04)	1.69(1.52)	676.56(96.03)
	EFS	Parigi	2.34(0.34)	0.4(0.06)	34(1.08)	116.5(6.41)	13.8(1.56)	18.88(1.01)	8.5(0.33)	0.43(0.13)	8.43(4.35)	339.06(59.48)
		Poso	2.55(0.63)	0.3(0.03)	39.75(2.95)	80.25(6.86)	11.73(0.78)	17.6(0.46)	7.6(0.18)	0.13(0.05)	73.44(65.22)	239.06(19.99)
		Sarjo	4.47(1.47)	0.27(0.05)	26.25(3.71)	76.25(11.9)	14(1.23)	16.13(0.55)	7.8(0.09)	0.21(0.1)	12.94(6.49)	803.13(69.15)

NF Number of fruits per area, *RI* Rate of infection, *NSF* Number of seeds per fruit, *WSF* weight of seeds per fruit, *DT* diameter of trunk, *LF* length of fruit, *DF* diameter of fruit, *AW* area of weeds, *DW* density of weeds, *DDPM* density of dead plant materials, *EFS* environmental friendly system

[a] Mean (standard error)

Table 3 Concentration of nutrients in cacao leaves from Sulawesi Island, Indonesia

Place	System	Location	*N* (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)
Inland	Conv.	Kulawi	1.49(0.12)[a]	0.18(0.01)	1.43(0.15)	0.90(0.10)	0.44(0.03)	0.12(0.01)	43.81(5.23)	64.54(7.54)	1532.62(250.33)	10.11(1.32)	28.13(2.56)
		Palolo	1.55(0.16)	0.16(0.01)	1.61(0.16)	1.20(0.12)	0.50(0.05)	0.13(0.01)	31.51(3.33)	76.18(8.53)	1523.60(210.21)	10.25(2.34)	34.36(4.32)
		Sidondo	1.62(0.21)	0.19(0.02)	1.88(0.19)	1.57(0.16)	0.56(0.04)	0.13(0.02)	43.67(6.29)	96.55(8.98)	1930.97(225.63)	8.81(1.12)	61.92(7.39)
	EFS	Kulawi	1.38(0.18)	0.19(0.02)	1.93(0.19)	1.24(0.14)	0.52(0.06)	0.13(0.01)	45.98(4.96)	71.80(7.27)	1435.97(154.52)	13.18(1.34)	29.2(2.21)
		Palolo	1.64(0.15)	0.17(0.01)	1.37(0.14)	1.14(0.12)	0.50(0.04)	0.13(0.02)	28.36(2.65)	79.01(6.25)	1580.15(185.25)	10.24(2.23)	34.51(3.23)
		Sidondo	1.51(0.13)	0.19(0.02)	1.65(0.16)	1.32(0.14)	0.52(0.03)	0.13(0.01)	44.04(4.67)	91.69(7.78)	1833.66(200.25)	11.11(1.89)	45.17(4.21)
Seacoast	Conv.	Parigi	1.64(0.17)	0.16(0.01)	1.81(0.18)	0.97(0.10)	0.54(0.04)	0.13(0.01)	48.06(5.11)	73.89(8.21)	2405.53(320.25)	9.67(1.09)	29.26(3.67)
		Poso	1.81(0.17)	0.20(0.02)	2.06(0.21)	1.07(0.12)	0.48(0.05)	0.12(0.02)	46.75(5.90)	82.92(9.13)	1658.40(185.13)	10.28(1.76)	41.16(4.28)
		Sarjo	1.53(0.15)	0.19(0.01)	1.56(0.16)	1.04(0.11)	0.73(0.06)	0.13(0.01)	81.49(9.98)	93.00(8.29)	1859.96(235.69)	9.10(1.09)	28.46(2.21)
	EFS	Parigi	1.60(0.15)	0.17(0.02)	1.80(0.18)	1.03(0.11)	0.54(0.05)	0.12(0.01)	47.31(5.67)	81.10(9.63)	2039.80(210.54)	10.20(1.76)	37.98(4.43)
		Poso	1.57(0.16)	0.23(0.01)	2.51(0.25)	1.44(0.14)	0.42(0.04)	0.13(0.02)	57.00(6.90)	81.80(9.41)	1635.91(165.74)	10.52(1.20)	39.37(4.13)
		Sarjo	2.11(0.23)	0.22(0.02)	1.49(0.15)	1.16(0.12)	0.67(0.07)	0.14(0.01)	46.26(6.09)	93.78(8.54)	1875.49(185.50)	10.54(1.45)	33.73(3.75)

EFS environmental friendly system

[a] Mean(standard error)

suggested a certain instability on inland (Kulawi, Palolo, and Sidondo) conventional system farms, and on seacoast (Parigi, Poso, and Sarjo) EFS farms, and conversely, the NBI might be stable in seacoast conventional systems and in inland EFS. This stability is represented by the NBI values, where those near the zero are equivalent to well nutrient balance in plants, whereas the higher values indicate nutrient in excess or deficiency. The DRIS values indicated that in inland areas, the Fe, Mn Zn, and K are limited by deficiency and in seacoast by an excess of Zn, P, and K. Soils that have low levels of organic matter and highly alkaline have shown to exhibit a low plant-available Zn (Sadeghzadeh 2013). However, the DRIS might vary according to the phenological stage, season, and the plant variety (de Matos et al. 2017; Gott et al. 2017). This was only a general estimation about the nutrition in the local cacao farms.

Among the ten agro-ecological parameters, some of them showed interesting results, such as RI, which indicated that cacao grown in inland locations and EFS seemed to have an advantage. Compared with other results (Wood and Lass 1992), our data clearly showed that the number and weight of marketable fruits, as well as yield, were significantly different depending on the location and system. Besides the yield, the fruit quality, represented by microbial flora, also differs in organic and conventional systems. For example, in some vegetables, organic management leads to less abundance of Enterobacteriaceae taxa (Leff and Fierer 2013). So, in this research, it is expected that the microbial flora on the surface of cacao cultivated in Sulawesi may be different from inland and seacoast areas, as well as from conventional and EFS. Furthermore, the availability of nutrients for microbes differs depending on environmental conditions (Jacobsen 2006); therefore, we believe that more studies are required to investigate how microbiota differ in EFS compared to conventional systems, and what their protective effects against fruit pathogens are.

Analyzing the relationship between agro-ecological indicators and plant mineral nutrition, the positive correlation shown between DDPM and some elements was the most remarkable, especially with N, Mg, and Fe. Weed presence indicators had negative correlation with Fe and P, and the higher utilization of herbicides can lead to decrease the weeds in conventional systems. Therefore, the higher weed presence may commit the uptake of these two elements. Fe also correlated to the number of fruits and dead plant materials, suggesting

Table 4 DRIS (Diagnosis and Recommendation Integrated System) index (a) and limiting sequence (b) of nutrients for each location and system of cacao farms on Sulawesi Island

a)

Place	System	Location	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
Inland	Conv.	Kulawi	− 0.22[a]	0.3	− 0.58	− 0.77	− 0.51	− 0.22	− 0.28	− 0.48	− 0.58	− 0.18	− 0.73
		Palolo	0.22	− 0.37	0.12	0.38	0.22	0.38	− 0.73	− 0.12	− 0.17	0.29	0.14
		Sidondo	0	− 0.14	0.26	− 0.06	0.21	− 0.94	− 0.12	0.41	0.33	− 0.83	1.71
	EFS	Kulawi	− 0.97	− 0.47	− 0.85	− 0.22	− 0.29	− 0.45	− 0.22	− 1.03	− 1.06	0.6	− 1.34
		Palolo	0.77	0.14	− 0.27	0.26	0.41	0.36	− 0.85	0.25	0.17	0.51	0.31
		Sidondo	− 0.87	− 0.65	− 0.71	− 0.1	− 0.49	− 0.57	− 0.53	− 0.34	− 0.39	− 0.56	0.21
Seacoast	Conv.	Parigi	0.74	− 0.13	0.64	− 0.09	0.56	0.23	0.44	0	0.37	0.29	− 0.18
		Poso	0.13	− 0.26	0.29	− 0.56	− 0.62	− 0.41	− 0.14	− 0.48	− 0.53	− 0.51	− 0.65
		Sarjo	− 0.35	− 0.31	− 0.49	− 0.42	0.08	− 0.09	1.22	0.19	0.12	− 0.81	− 0.86
	EFS	Parigi	0.02	− 0.46	0.18	− 0.32	0.22	− 0.11	0.16	− 0.17	0.54	− 0.14	0.15
		Poso	0.31	1.06	1.12	1.04	− 0.32	0.48	0.87	0.22	0.12	0.38	0.58
		Sarjo	0.58	1.61	0.36	0.85	0.77	1.25	0.79	1.33	1.18	1.13	0.61

b)

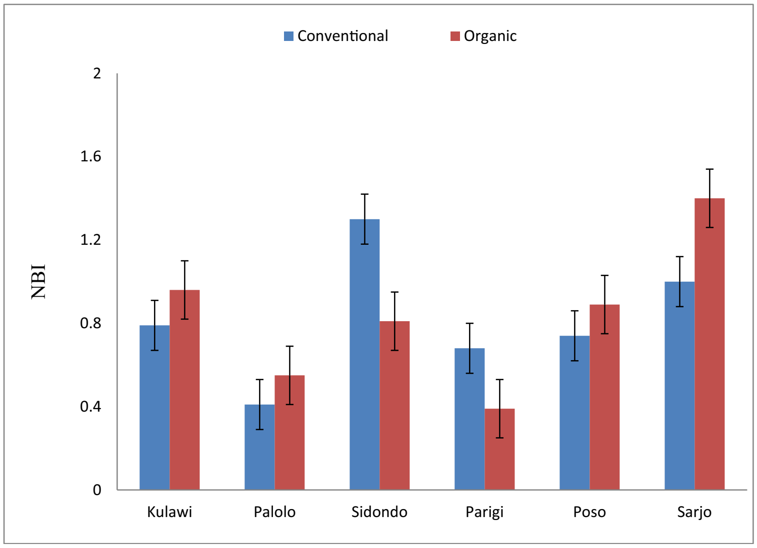
Place	System	Location	Limiting sequence
Inland	Conv.	Kulawi	Ca > B > K > Mn Mg > Fe > Zn > N = S > Cu > P
		Palolo	Zn > P > Mn > Fe = K > B > N = Mg > Cu > Ca > S
		Sidondo	S > Cu > P > Zn > Ca > N > Mg > K > Mn > Fe > B
	EFS	Kulawi	Mn > Fe > B > N > K > P > S > Mg > Zn = Ca > Cu
		Palolo	Zn > K > P > Mn > Fe > Ca > B > S > Mg > Cu > N
		Sidondo	N > K > P > S > Cu > Zn > Mg > Mn > Fe > Ca > B
Seacoast	Conv.	Parigi	B > P > Ca > Fe > S > Cu > Mn > Zn > Mg > K > N
		Poso	B > Mg > Ca > Mn > Cu > Fe > S > P > Zn > N > K
		Sarjo	B > Cu > K > Ca > P > N > S > Mg > Mn > Fe > Zn
	EFS	Parigi	P > Ca > Fe > Cu > S > N > B > Zn > K > Mg > Mn
		Poso	Mg > Mn > Fe > N > Cu > S > B > Zn > Ca > P > K
		Sarjo	K > N > B > Mg > Zn > Ca > Cu > Mn > S > Fe > P

[a] Index value compared to other nutrients

that there is no trade-off between these parameters. It is reasonable, therefore, to assert that in order to increase yield and ameliorate the plant mineral nutrition, farmers should severely control weeds and use the dead leaves of cacao as a ground cover in cacao plantations. This result may reflect that leaves and branches can control the weeds by influencing the absorption of sunlight and the soil microbial community (Turner et al. 2013), which may indirectly affect the plant yield and mineral nutrition due to an improvement of nutrient dynamics in soil through microbial activity.

On Sulawesi Island, the farming practices within a given village are usually consistent. However, local farms have suffered from relatively consistent levels of production loss, mainly due to fungal rot, pests, and heavy rains. Some farmers estimated that around 60% of their crop was affected, and some considered that cacao farming was no longer profitable (Cicuzza et al. 2012). Most farmers used fertilizers, herbicides, pesticides, and fungicides, aiming to reduce the impact of pests and pathogens and boost yields. Further studies could provide more insight into the difference between the two systems in inland and coastal locations,

Fig. 2 Comparison of nutritional balance index (NBI) between each location and system on Sulawesi Island



especially regarding the minimization of cacao losses due to diseases with a minimum of chemical pesticides that might increase the local net income of farmers.

Conclusion

Overall, this research confirms that among the agro-ecological indicators, the number of infected fruits and the density of dead materials were the most representative to explain the current situation of cacao in Sulawesi Island, Indonesia. In addition, the effects of EFS on production were more localized than generalized, i.e., the observation of EFS on improvement was individually for each area. The correlations between the agro-ecological parameters and plant mineral nutrition also proved that the weed area and density could indicate the productivity in each area. The plants were most limited by Ca and B, whereas the P was more in excess.

Table 5 Correlations between agro-ecological parameters on the cacao farm and mineral nutrition in leaves of cacao on Sulawesi Island

	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
NF	0.172	− 0.021	− 0.055	0.037	− 0.005	0.011	− 0.033	0.372**	0.027	− 0.247	0.217
RI	0.156	− 0.012	0.047	− 0.010	− 0.120	0.024	0.001	0.026	− 0.012	− 0.176	0.282
NSF	− 0.167	− 0.001	0.176	0.034	0.020	− 0.085	0.149	− 0.231	0.180	− 0.074	− 0.027
WSF	0.015	− 0.152	0.008	− 0.237	− 0.063	− 0.124	− 0.155	− 0.423**	0.227	0.062	− 0.244
DT	0.069	− 0.110	0.082	− 0.051	− 0.010	− 0.119	0.034	− 0.105	0.018	− 0.268	0.020
LF	0.168	0.170	0.295*	− 0.008	0.163	0.032	0.193	0.125	0.289*	− 0.012	0.161
DF	0.187	− 0.197	0.051	− 0.057	− 0.090	− 0.029	− 0.266	− 0.014	.252	− 0.032	0.276
AW	− 0.065	− 0.302*	− 0.142	− 0.298*	− 0.099	− 0.042	− 0.309*	− 0.510**	0.066	0.122	− 0.261
DW	− 0.227	0.098	0.179	− 0.227	− 0.126	− 0.047	0.043	− 0.547**	0.116	0.331*	− 0.335*
DDPM	0.326*	0.139	− 0.258	0.057	0.340*	0.131	0.240	0.538**	0.064	− 0.180	− 0.024

NF number of fruits per area, *RI* rate of infection, *NSF* number of seeds per fruit, *WSF* weight of seeds per fruit, *DT* diameter of trunk, *LF* length of fruit, *DF* diameter of fruit, *AW* area of weeds, *DW* density of weeds, *DDPM* density of dead plant materials

*Correlation is significant at the 00.05 level (two-tailed); **correlation is significant at the 00.01 level (two-tailed). Pearson correlation

Acknowledgements We would like to thank the cacao farmers of Sulawesi, Indonesia, for allowing us access to their farms and for the information and samples they provided. We would also like to thank the students at Tadulako University who assisted us with the sampling and analysis. Finally, we are thankful to Dr. G.M. de Almeida, of Kyoto University, Japan, for her critical and constructive comments on this manuscript. This project was supported by the bilateral cooperation program between JSPS (Japan) and DHGE (Indonesia) and another grant of International collaboration and Publication (KLN) from the Indonesian Government.

References

Ahmad Z, Khan SM, Abd_Allah EF et al (2016) Weed species composition and distribution pattern in the maize crop under the influence of edaphic factors and farming practices: a case study from Mardan, Pakistan. Saudi J Biol Sci 23:741–748. https://doi.org/10.1016/j.sjbs.2016.07.001

Armengot L, Barbieri P, Andres C et al (2016) Cacao agroforestry systems have higher return on labor compared to full-sun monocultures. Agron Sustain Dev 36:70. https://doi.org/10.1007/s13593-016-0406-6

Bellomonte G, Constantine A, Giammariolo S (1987) Comparison of modified automatic dumas method and the traditional Kjeldahl method for nitrogen determination in infant food. JAOAC 70:227–229

Cicuzza D, Clough Y, Tjitrosoedirdjo SS, Kessler M (2012) Responses of terrestrial herb assemblages to weeding and fertilization in cacao agroforests in Indonesia. Agrofor Syst 85:75–83. https://doi.org/10.1007/s10457-011-9456-6

de Araujo QR, Baligar VC, de Loureiro GAHA et al (2017) Impact of soils and cropping systems on mineral composition of dry cacao beans. J Soil Sci Plant Nutr 17:410–428

de Matos GSB, Fernandes AR, Wadt PGS, et al. (2017) The use of DRIS for nutritional diagnosis in oil palm in the state of Pará . Rev Bras Ciência do Solo 41, e0150466. https://doi.org/10.1590/18069657rbcs20150466

de Matos GSB, Fernandes AR, Wadt PGS et al (2018) Dris calculation methods for evaluating the nutritional status of oil palm in the eastern Amazon. J Plant Nutr 41:1–12. https://doi.org/10.1080/01904167.2018.1434199

Gott RM, Aquino LA, Clemente JM et al (2017) Foliar diagnosis indexes for corn by the methods diagnosis and recommendation integrated system (DRIS) and nutritional composition (CND). Commun Soil Sci Plant Anal 48:11–19. https://doi.org/10.1080/00103624.2016.1253714

Indonesia Investments (2015) Cocoa. http://www.indonesia-investments.com/business/commodities/cocoa/item241. Accessed 1 Feb 2015

Isaac RA, Johnson WC (1985) Elemental analysis of plant tissue by plasma emission spectroscopy: collaborative study. JAOAC 68:499–505

Jacobi J, Schneider M, Pillco Mariscal M et al (2015) Farm resilience in organic and nonorganic cocoa farming systems in Alto Beni, Bolivia. Agroecol Sustain Food Syst 39:798–823. https://doi.org/10.1080/21683565.2015.1039158

Jacobsen BJ (2006) Biological control of plant diseases by phyllosphere applied biological control agents. In: Bailey MJ, Lilley AK, Timms-Wilson TM, Spencer-Phillips PTN (eds) Microbial ecology of aerial plant surfaces. CAB International, pp 133–149

Juhrbandt J, Duwe T, Barkmann J et al (2010) Structure and management of cocoa agroforestry systems in central Sulawesi across an intensification gradient. In: Tscharntke T, Leuschner C, Veldkamp E et al (eds) Tropical Rainforests and Agroforests under Global Change. Springer, Berlin, pp 115–140

Kemmitt SJ, Wright D, Goulding KWT, Jones DL (2006) pH regulation of carbon and nitrogen dynamics in two agricultural soils. Soil Biol Biochem 38:898–911. https://doi.org/10.1016/j.soilbio.2005.08.006

Leff JW, Fierer N (2013) Bacterial communities associated with the surfaces of fresh fruits and vegetables. PLoS One 8: e59310

Marschner H (2011) Marschner's mineral nutrition of higher plants. Academic Press, London

Nemes NS (2009) Comparative analysis of organic and non-organic farming systems: a critical assessment of farm profitability. Food and Agriculture Organization of the United Nations. In: Nat. Resour. Manag. Environ. Dep. http://www.fao.org/3/a-ak355e.pdf. Accessed 1 Jan 2017

Petit S, Boursault A, Le Guilloux M et al (2011) Weeds in agricultural landscapes. A review. Agron Sustain Dev 31: 309–317. https://doi.org/10.1051/agro/2010020

Sadeghzadeh B (2013) A review of zinc nutrition and plant breeding. J Soil Sci Plant Nutr 13:905–927

Saito K, Linquist B, Johnson DE et al (2008) Planted legume fallows reduce weeds and increase soil N and P contents but not upland rice yields. Agrofor Syst 74:63–72. https://doi.org/10.1007/s10457-008-9149-y

Schneider M, Andres C, Trujillo G et al (2017) Cocoa and total system yields of organic and conventional agroforestry vs. monoculture systems in a long-term field trial in Bolivia. Exp Agric 53:351–374. https://doi.org/10.1017/S0014479716000417

Schwendenmann L, Veldkamp E, Moser G et al (2010) Effects of an experimental drought on the functioning of a cacao agroforestry system, Sulawesi, Indonesia. Glob Chang Biol 16:1515–1530. https://doi.org/10.1111/j.1365-2486.2009.02034.x

Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485:229–232

Turner TR, James EK, Poole PS (2013) The plant microbiome. Adv Bot Res 69:1–10 doi: 10.1186

Wadt PGS (2014) Nutritional status of Eucalyptus grandis clones evaluated by critical level and dris methods. Rev Arvore 28: 15–20

Wadt PGS, de Novais RF, Alvarez Venegas VH, Braganca SM (1999) "DRIS" application alternatives for the coffee (Coffea canephora Pierre) crop. Sci Agric 56:83–92

Wadt PGS, Silva DJ, Maia CE et al (2007) Modelagem de funcoes no calculo dos indices DRIS. Pesqui Agropecu Bras 42:57–64

Wood GAR, Lass R (1992) Cocoa, fourth. Longmann Press, London

Xue K, Wu L, Deng Y et al (2013) Functional gene differences in soil microbial communities from conventional, low-input, and organic farmlands. Appl Environ Microbiol 79:1284–1292. https://doi.org/10.1128/AEM.03393-12