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Adding Organic Matter Enhanced the Effectiveness of Silicate Rock Fertilizer for Food Crops Grown on Nutritionally Disorder Soils: A Glasshouse Assessment

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ABSTRACT

A glasshouse experiment was carried to identify effects of the application rate of ground silicate rock as a multi-nutrient fertilizer (SRF) with and without organic matter (OM) on growth and nutrient status of food crops (rice, corn, and soybean). Those crops were grown on 3 different soils in 2 cropping patterns, *i.e.*, rice – soybean and corn – soybean, providing 6 experimental sets. A completely randomized design was applied in each experimental set. The treatment in each set consisted of 3 rates of SRF (5, 10, and 15 g kg^{-1}), those 3 rates + 5 g kg^{-1} of OM, and a control (without adding SRF or OM). The first crops (rice and corn) were grown up to 65 days, while the second crop (soybean) was up to 40 days. Results indicated that for crops grown on less fertile soils, the application of SRF only slightly increased growth of crops, mainly of the 2nd crops, and adding OM greatly increased the growth of both the 1st and 2nd crops. In those experimental sets, about 60 – 80% of the variation of crop growth was significantly determined by concentration of Cu and several other essential nutrients in crop tissue. In contrast, the growth for crops grown on more fertile soils was not affected by the application of SRF or/and OM. It was concluded that adding OM enhanced the effectiveness of SRF as a multi-nutrient fertilizer, and that may be used as an appropriate multi-nutrient fertilizer or general ameliorant to sustain soil quality and remediate the nutritionally disorder soils.

Keywords: Nutritionally disorder soils, organic matter, silicate rock fertilizers

INTRODUCTION

Ground Silicate rock has been proposed as a multi-nutrient fertilizer or general soil ameliorant by many researchers (Leonardos *et al*. 1987, 2000; Hinsinger *et al*. 1996; Conventry *et al*. 2001; van Straaten 2006; and Priyono and Gilkes 2008). Up to the present day, however, the use of silicate rock fertilizer (SRF) in agricultural practices is so limited. In addition to the conflicting results of the researches dealing with SRF, the rarely use of SRF by farmers was mostly due to the slow release of nutrients from SRF into soil solution (Hinsinger *et al*. 1996), consequently a large quantity (> 10 Mg ha^{-1}) of the fertilizers must be applied. Efforts to improve the effectiveness of SRF application have been carried out. For example, Lim and Gilkes (2002), Harley (2003), and Priyono (2005) applied high-energy milling to produce SRF. The method was effective in speeding up nutrient dissolution from SRF to soil solution as well as agronomic effectiveness of SRF application. However, the required rates of SRF application (1 – 5 Mg ha^{-1}) were still much higher than commonly applied inorganic fertilizers by farmers.

Several conflicting results in evaluating the true effectiveness of SRF on farm level may be due to the differences in particle size of SRFs and methodological approaches applied by different researchers. Most experiments were conducted only on the basis of SRF as a source of an essential nutrient for plant. For examples, the ball-milled hornblende (Harley 2003) and basalt and dolerite (Priyono and Gilkes 2008) were evaluated only as a Ca or/and Mg fertilizer. In other experiments, ground-mica (Weerasuriya *et al*. 1993), ball-milled feldspars (Harley 2003) and gneiss (Priyono 2005) were used as K fertilizer. In those researches, the possibility of significant supply of other nutrients from applied SRFs to crop was neglected. The liming effect of SRFs that surely determined soil-nutrient status for plants was also ignored. An addition to the ignored aspects was the present of large quantity of plant-available Si from dissolution of SRFs into soil solution. The plant-available Si was beneficial mainly for grasses (Ma and Takahashi 2002), but it might be restrict the growth of non grasses (Priyono and Gilkes 2008). Due to the multi functions of SRF, the true effectiveness of SRF application needs to be evaluated on the basis of confounding effects of all functions of SRF to crop growth or/and soil fertility.

In the soil system, Priyono *et al*. (2009) found that dissolution of nutrients from SRF was stimulated by soil organic content. Based on this finding, combining SRF and organic matter (OM) may be the most appropriate method. Both materials could be beneficial for crop growth and soil quality. To prove the promising beneficiaries of using SRF and OM in soil – plant systems, a glasshouse experiment was conducted.

The main objective of the research was to identify effects of the application rate of SRF with and without adding organic matter (OM) as a multi-nutrient fertilizer to growth and nutritional status of food crops (rice, corn, and soybean).

MATERIALS AND METHODS

Soil and Fertilizers

Soil samples were the 20-cm tops of Typic Eutrudepts (KGEV) taken from Griyorejo, Gresik - East Java, Typic Hapludalfs (JEJZd) from Wonosalam, Mojokerto - East Java, and Lithic Ustipsamments (LDDA) from Kayangan, North Lombok - NTB. The notations or acronyms used for the soil types were referred to Keys of Soil Taxonomy (Soil Survey Staff 2010), and those were used throughout in this paper. Soil samples were air dried, lightly grounded to breakdown large aggregates, and screened to pass a 2-cm stainless steel sieve. Several chemical properties of the soils are presented in Table 1.

Silicate rock fertilizer (SRF) was the ball-milled basaltic rock originated from Mt. Rinjani in Lombok Island. For the detail procedure of milling and elemental and mineralogical composition of SRF, and analytical methods accordingly may refer to Priyono *et al*. (2009). Organic matter (OM) was a mixture of dry horse and chicken wastes at a ratio of 1:1 (w/w), screened to pass a 1-mm sieve. The OM was characterized by: the C/N ratio was 12; totals of N, Ca, K, and Fe were 1.40, 0.09, and 1.05 %; and totals of Zn and Cu were 99 and 56 mg kg^{-1}, respectively.

Glasshouse Experiment

Six sets of experiment were prepared. Three experimental sets were for growing rice (the first crop) and soybean (the second crop) consecutively on a soil type for each experimental set; and the other 3 sets were for growing corn (the first crop) and soybean (the second crop). A completely randomized design was applied to each set of experiment with the treatment consisting of 3 rates of SRF (5, 10, and 15 g kg^{-1}) without OM, and 3 of those rates of SRF mixed with 5 g kg^{-1} OM, and a control or reference (no adding SRF or OM), all were in duplicates. The treatments were applied only to the first crop in each set of experiment. The

Table 1. Main chemical properties of soils used in the experiments

No	Soil Properties	Methods/ Instrument/ Extraction	Unit	Type of Soils		
				Typic Eutrundepts (KGEV)	Typic Hapludalfs (JEJZd)	Lithic Ustipsamments (LDDA)
1.	pH_{H2O} (1:5)	pH-meter	-	6.93	5.37	5.87
2.	EC (1:5)	EC-meter	$\mu S\ cm^{-1}$	84.60	54.97	28.70
3.	CEC	$NH_4OAc.1N$ pH 7	$cmol_c\ kg^{-1}$	31.31	25.64	4.52
4.	Exchangeable:	$NH_4OAc.1N$ pH 7				
	- Na^+		$cmol_c\ kg^{-1}$	0.11	0.06	0.10
	- K^+		$cmol_c\ kg^{-1}$	0.13	0.47	0.46
	- Ca^{+2}		$cmol_c\ kg^{-1}$	24.54	11.31	3.10
	- Mg^{+2}		$cmol_c\ kg^{-1}$	10.44	2.39	0.90
5.	Extractable:	Acetic + Citric				
	- Fe	Acids 0.01*M*	$mg\ kg^{-1}$	198.49	165.57	69.46
	- Zn		$mg\ kg^{-1}$	0.16	0.69	2.17
	- Cu		$mg\ kg^{-1}$	0.40	0.80	0.32
6.	Extractable Si	Blue methol	$mg\ kg^{-1}$	169.70	314.70	87.90

non draining pots with capacity of 5L were used in this experiment. Each pot was fill with 3 kg air-dried soil and was mixed with SRF or/and OM accordingly to the treatment.

Prior to growing rice, soil and SRF or/and OM were mixed, saturated and mudded with deionized water, and were incubated for a week. Rice seed (var. IR 46) was germinated for 3 weeks in another pot, and 3 germinates were transplanted into each pot. Basal fertilizers (10 g kg^{-1} of N in form of NH_4NO_3 and 5 g kg^{-1} of P_2O_5 in form of KH_2PO_4) were applied in the second day after planting (dap), and another 10 g kg^{-} of N was applied at 35 dap. During the growing period of rice, soil was flooded and maintained at 2 – 5 cm obove soil surface. For growing corn, soil and SRF or/and OM were mixed, moisten and maitanined at about field capacity throughout the growing period. A week after equilibration period, 2 seeds of corn (var. Pioneer) were planted. Basal fetilizers for corn (10 g kg^{-1} of N and 5 g kg^{-1} of P_2O_5) were applied at 14 dap and another 10 g kg^{-1} of N was at 35 dap.

Biomass of rice and corn was harvested in 60 dap by cutting the plants just above soil surface, oven-dried at 60^o C for 3 weeks, weighted, and ground to pass a 1-mm sieve. Two weeks after harvesting the first crops (rice and corn), two seeds of soybean (var. Local - Lombok) were planted at about 1-cm depth in each pot (for all sets of experiment) without adding any fertilizer. Soil moisture was maintanined at about field capacity during the whole growing period. Biomass of soybean was harvested in 45 dap, oven dried, and weighted. Sub sample of biomass was taken and then ground for analyses of nutrient content in the plant tissue.

Analytical Methods

Soil EC and pH_{H2O} (1:5) were measured consecutively at clear suspension by using EC-meter and pH-meter, respectively. Total content of soil C-organic was identified by oxidation with $K_2Cr_2O_7$ (Walkley and Black 1934), cation exchange capacity (CEC) with 1M ammonium acetate (NH_4OAc) buffered at pH 7 as an extracting solution (Thomas 1982), and concentration of exchangeable base cations (Ca, Mg, K, and Na) in the filtrate was identified by using AAS. In the measurement of Ca concentration, 0.1% La solution was added as a suppressant.

The quantity of Fe, Zn, Cu, and Si were extracted by using 0.01M citric + oxalic acids (1:1). A 5 kg of soil in a 250mL-plastic bottle was mixed with 25mL of the extracting solution, shaken on a rotary shaker for 60 minutes and filtered. Concentrations of Fe, Zn, and Cu in the filtrate were measured with AAS, and that for Si was identified with a modified blue methol method (Nayar *et al*. 1975).

The main element composition of OM and plant biomass were analyzed using wet digestion method ($HClO_4$ + H_2SO_4), and the concentrations of Ca, Mg, K, Fe, Mn, Zn, and Cu in the filtrate were measured with AAS, whereas that for Si was by using a modified blue methol method (Nayar *et al*. 1975).

Statistical Analyses

Analyses of variant were carried out to identify effects of the application rate of SRF with and without OM on plant growth (dried weight of biomass) and concentration of several nutrients (Ca, Mg, K, Fe, Mn, Zn, and Cu) in plant tissue. The relationships between weight of dry biomass and concentration of nutrients in plant tissue were analyzed by a multivariate method (a forward stepwise procedure at ridged lambda of 0.05) using a software of Statistica 6.

RESULTS AND DISCUSSION

Plant Growth

The mean values of dry weight of biomass, as an indicator of plant growth, in relation to the application rates of SRF with and without OM are presented in Figures 1 and 2. Statistically, the application of SRF with and without OM significantly affected the biomass of crops grown on soil KGEV, but that did not for biomass of crops grown on soils LDDA and JEJZd . The different responses of crops to the fertilizer application were most probably due to the differences in nutritional status of those soils used in this experiment.

For experiments using soil KGEV, the trends of plant growth in both cropping patterns, in relation to the application rate of SRF and SRF + OM, were quite similar. The application of SRF without OM tended to decrease biomass of the first crops (rice and corn), but slightly increased of that for the second crop (soybean) in both cropping patterns. The application of SRF + OM, on the other hand, greatly increased the growth of the 1^{st} and 2^{nd} grown crops on soil KGEV. In the cropping pattern of 'rice – soybean', adding SRF + OM increased biomass of rice and soybean up to about 50 and 75%, respectively; while in the cropping pattern of 'corn – soybean', the growths of corn and soybean

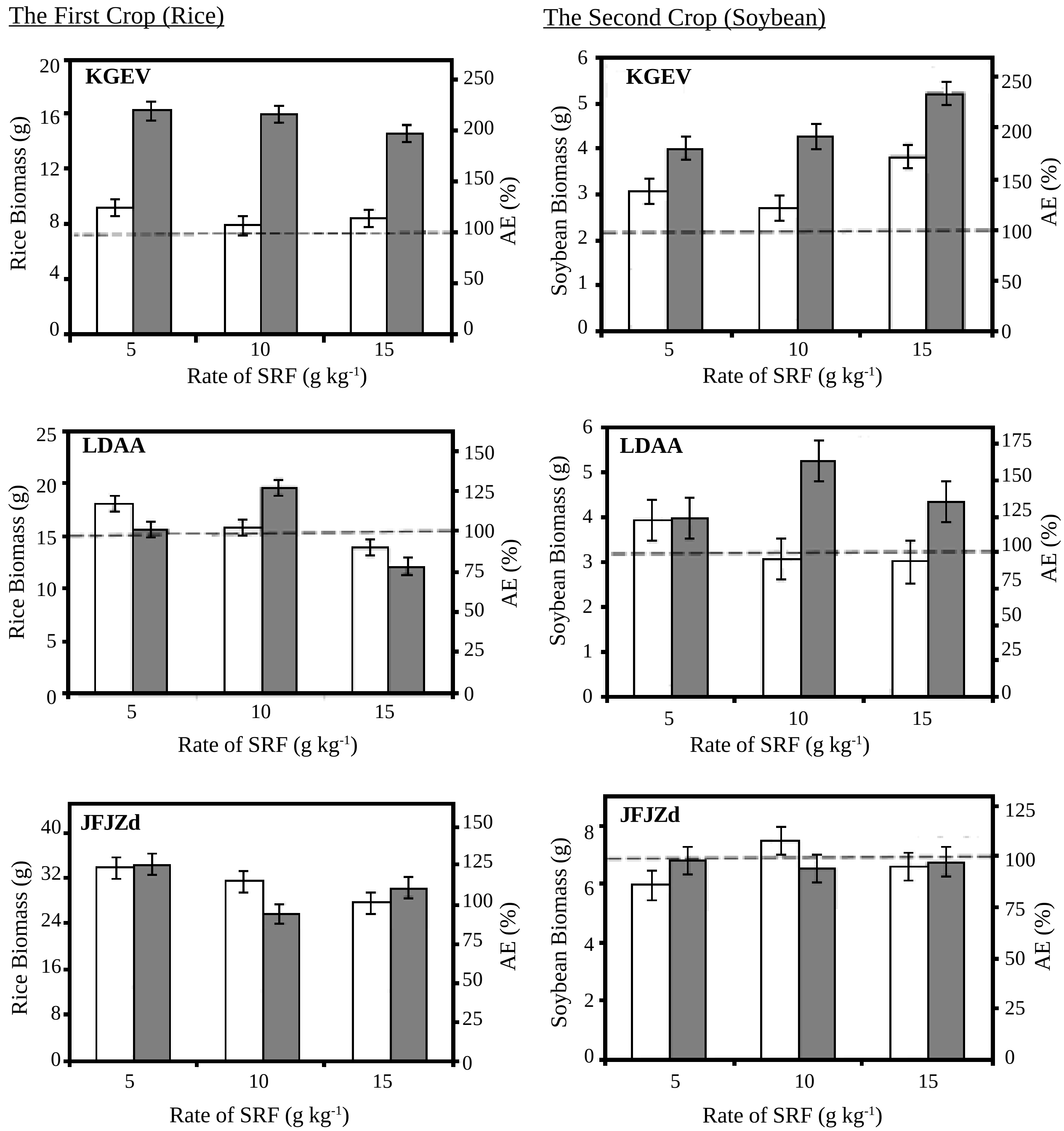

Figure 1. The relationships between mean dry weight of biomass and agronomic effectiveness (AE) relative to control (dashed lines) for the first (left) and second (right) crops grown on the soils KGEV (Typic Eutrundepts from Griyorejo), LDDA (Lithic Ustipsamments from Kayangan), and JEJZd (Typic Hapludalfs from Wonosalam), and with the application rate of silicate rock fertilizer (SRF) without (□) and with OM 5 g kg^{-1} (■), in the cropping pattern of 'rice – soybean'. The error bars are standard error of mean.

increased about 21 and 54 %, respectively, relative to the control.

To identify the relative fertility level of the soils, the mean values of dry biomass of untreated crop (control) grown on those different soils were compared and arranged orderly. The orders of soil type, associating to the values of that parameter, in each cropping pattern were the same or consistent, *i.e.* JEJZd > LDDA > KGEV. In the cropping pattern of 'rice – soybean', rice biomass for the control grown on soils JEJZd, LDDA, and KGEV respectively were 27.3, 17.4, and 9.8 g, and those for soybean were 7.0, 3.2, and 3.0 g. In the cropping pattern of 'corn – soybean', corn biomass in the experiments using soils JEJZd , LDDA, and KGEV, respectively were 41.0, 32.8, and 28.4 g; and those for soybean were 7.1, 5.0, and 3.7 g. Based on those trends, soil JEJZd (from Wonosalam) may be

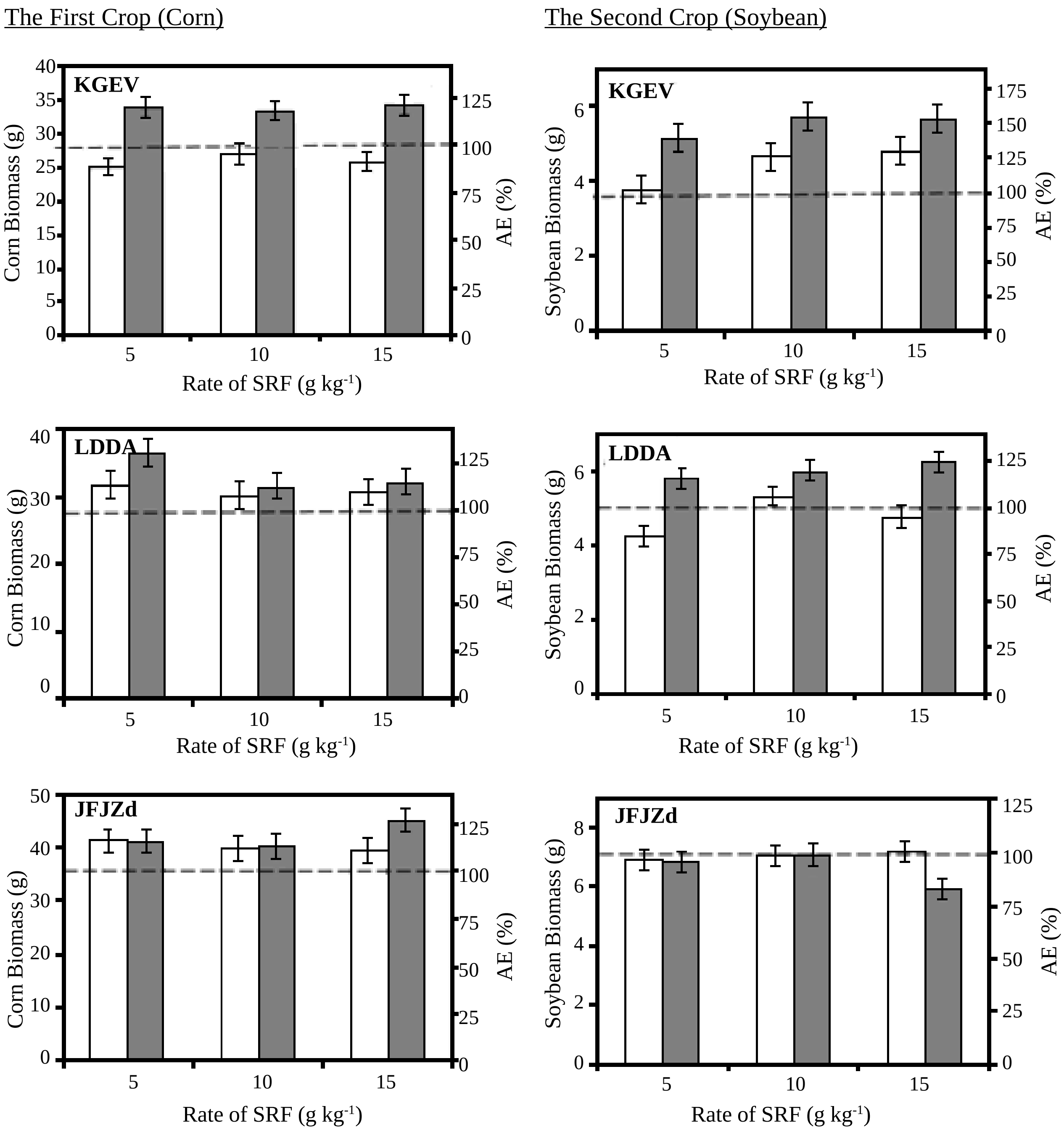

Figure 2. The relationships between mean dry weight of biomass and agronomic effectiveness (AE) relative to control (dashed lines) for the first (left) and second (right) crops grown on the soils KGEV (Typic Eutrundepts from Griyorejo), LDDA (Lithic Ustipsamments from Kayangan), and JEJZd (Typic Hapludalfs from Wonosalam), and with the application rate of silicate rock fertilizer (SRF) without (□) and with OM 5 g kg^{-1} (■), in the cropping pattern of 'corn – soybean'. The error bars are standard error of mean.

interpreted as the most fertile soil, followed by soil LDDA (from Kayangan), while soil KGEV (from Griyorejo) was as the least fertile (nutritionally disorder) soil. In other word, the less fertile the soil, the more its response to the application of SRF or SRF + OM. This result was parallel to the finding of Priyono and Gilkes (2008) showing that the most effective SRF application was on acidic or/and nutritionally disorder soils. A further question was 'which were nutrients or what kind of disorder properties of soil KGEV causing this soil was more responsive than the other soils to the application of SRF or SRF + OM?'

Referring to Leibig's lesson, the levels of optimum, deficient, or toxic of essential nutrients for the growth of a crop are not only affected by the quantity of individual plant-available nutrient, but also by its relative proportion to that of other essential nutrients. A simple way to provide an appropriate answer for the above question is by identifying the relationships between crop growth and concentration of nutrients in plant tissue by using multivariate analysis, which is described in the following section.

Nutrient Concentration in Plant Tissue

There were very large data of nutrient (Ca, Mg, K, Fe, Zn, and Cu) concentration in plant tissue, so that only of those in the experimental sets using soil KGEV are presented in Tables 2a and 2b as examples. Two main points which may be

Table 2a. Mean concentration of nutrients in plant tissue in the experiments using soil KGEV (Typic Eutrundepts) with cropping pattern of 'rice – soybean'.

No	Treatment		Nutrients					
	SRF	OM	Ca	K	Si	Fe	Zn	Cu
	…… ($g\ kg^{-1}$) …..		.... (%) ………..			……….. ($mg\ kg^{-1}$) …..…		
			The First Crop (Rice)					
1.	0	0	0.03	0.44	3.25	192	33	9
2.	5	0	0.03	0.56	3.11	167	31	16
3.	10	0	0.03	0.55	2.81	195	26	13
4.	15	0	0.02	0.47	2.72	29	21	7
5.	5	5	0.02	0.43	2.91	44	26	4
6.	10	5	0.03	0.48	2.95	73	38	8
7.	15	5	0.02	0.38	3.45	4	26	3
			The Second Crop (Soybean)					
1.	0	0	2.15	0.99	0.03	96	25	3
2.	5	0	2.48	0.95	0.13	98	32	3
3.	10	0	2.69	0.94	0.22	135	27	2
4.	15	0	2.56	1.04	0.05	543	34	2
5.	5	5	2.36	0.98	0.04	106	26	1
6.	10	5	2.45	1.02	0.04	119	24	3
7.	15	5	2.29	0.99	0.02	214	24	1

Table 2b. Mean concentration of nutrients in plant tissue in the experiments using soil KGEV (Typic Eutrundepts) with cropping pattern of 'corn – soybean'.

No	Treatment		Nutrients					
	SRF	OM	Ca	K	Si	Fe	Zn	Cu
	…… ($g\ kg^{-1}$) …..		.... (%) ………..			……….. ($mg\ kg^{-1}$) …..…		
			The First Crop (Corn)					
1.	0	0	0.04	0.22	0.28	32	18	4
2.	5	0	0.03	0.27	0.18	74	16	4
3.	10	0	0.03	0.25	0.24	51	20	4
4.	15	0	0.05	0.26	0.37	188	17	4
5.	5	5	0.02	0.30	0.16	162	17	3
6.	10	5	0.03	0.31	0.39	28	16	4
7.	15	5	0.04	0.31	0.37	23	24	3
			The Second Crop (Soybean)					
1.	0	0	3.08	0.83	0.14	278	46	2
2.	5	0	3.02	0.86	0.03	143	38	1
3.	10	0	2.65	0.82	0.16	92	31	2
4.	15	0	2.82	0.78	0.11	70	36	1
5.	5	5	2.65	0.77	0.14	111	38	2
6.	10	5	2.88	0.86	0.10	123	38	1
7.	15	5	2.56	0.77	0.11	90	32	1

Table 3. Summarized results of multivariate analysis between weigh of dry biomass and concentration of several nutrients in plant tissue grown on the soil KGEV (Typic Eutrundepts).

Crop	Equation*	R^2	Contribution (%)					
			Ca	K	Si	Fe	Zn	Cu
	Cropping Pattern 'Rice – Soybean'							
Rice	Biomass = 6.04 – 0.61 Cu + 0.58 Zn – 0.39 Fe	0.83	-	-	-	12	26	46
Soybean	Biomass = 5.12 – 0.55 Si – 0.42 Cu	0.63	-	-	47	-	-	16
	Cropping Pattern 'Corn – Soybean'							
Corn	Biomass = 25.51 + 0.52 K – 0.40 Cu	0.72	-	61	-	-	-	11
Soybean	Biomass = 13.62 – 0.70 Ca – 0.33 Cu	0.60	48	-	-	-	-	12

*Unit of biomass was in g pot^{-1}; Ca, K, and Si was in %; Fe, Zn, and Cu was in mg kg^{-1}.

interpreted from all data of nutrient concentration in plant tissue are as follows.

1. Statistically, the application rate of SRF with or without OM significantly affected the concentration of most nutrients in plant tissue.
2. There was no certain trend for the concentration of each nutrient in crop tissue in relation to the application rate of SRF with or without OM.

To provide appropriate answer for the question as mentioned in above section, a multivariate analysis was carried out. Since the treatment significantly affected only for crops grown on soil KGEV, this multivariate analysis was run only for data of the experiments using soil KGEV. Results of the analysis are presented in Table 3.

Nutrient concentration in plant tissue was indicative enough to evaluate the nutritional status of those crops (Table 3). About 60 to 83% for the variation of plant growth was significantly determined by concentration of nutrients in plant tissue. The level of the nutrients following a negative sign in the equations could be interpreted that those nutrients were at toxic level for growth of the crops. Inversely, for those following a positive sign could be interpreted that the concentration of the nutrients was in deficient level for growth of the crop. For an example, in the equation 1 (the first row in Table 3), about 83% of the variation of rice growth was determined by concentrations of Cu and Fe (due to their toxic levels) as well as by concentration of Zn (due to its deficient level) in plant tissue. Similar interpretation may be applied for the remaining equations. However, care should be taken in interpreting such equations. Each equation statistically is valid only for a certain soil condition or a range of soil nutrient quantity. Moreover, the effect of nutrient concentration to plant growth may not be counted as the effect of individual nutrient, but as the confounding effect of those nutrients presented in each equation.

CONCLUSIONS

The application of basaltic-silicate rock fertilizer increased the growth of food crops (rice, corn, and soybean) grown on the nutritionally disorder soils, but did not or less effects for those grown on the fertile soils. In addition, the effect of the rock fertilizer application was enhanced by adding organic matter. The concentration of essential nutrients in crop tissue greatly (60 – 80 %) determined the variation of crop growth for those grown on nutritionally disorder soils; and the level of Cu in plant tissue was a common determining factor. Importantly, the application of SRF with or without OM improved soil quality for short and long terms. Practically, ball-milled silicate rock + organic matter may used as an effective multi-nutrient fertilizer, mainly applied to the nutritionally disorder soils.

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