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Effects of the combination of cultivars and organic amendments for improving the resistance of water shortage in coffee

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Abstract

This study is aimed at studying the influence of organic fertilization on coffee growth and its resistance to drought. The experiment was carried out on young coffee plantlets in a greenhouse in Viet Nam and compared three varieties (Arabica L, Robusta TR9 and Robusta M38) and two types of organic amendments (compost or vermicompost). This study showed that both compost and vermicompost aided in the increase of soil chemical properties and above-ground plant biomass an as a comparison with chemical fertilizer. The vermicompost amendment has higher effect than compost could be observed for Arabica variety in term of soil organic carbon, total P, available N forms ($N\text{-}NH_4$) except available K and shoot biomass weight ($p<0,05$), with no different between two Robusta varieties TR9 & M38 ($p>0,05$). Interestingly, the plantlets fertilized with organic amendments had lower (7 days) for resistance to drought than mineral chemical (9 days.) Therefore, these results suggest that the resistance of coffee plantlets to drought is reduced if the nursery growing media contains compost or vermicompost.

Keywords: Coffee, Drought, Compost, Vermicompost, Nursery growing media

1. Introduction

Coffee is an extremely important cash crop for millions of small farmers in Latin America, Asia and Africa [1,2]. In Viet Nam, the largest producer of Robusta beans in the world, the cultivation of coffee is very strategic with 63,000 stakeholders dependent on its production. However, its coffee production is suffering from rising temperatures and expectedly more frequent droughts, alongside the degradation of lands after decades of intensive cultivation and the almost exclusive utilization of mineral fertilizers [3]. Roughly a fifth of Viet Nam's total plantation has been damaged by water shortages, which should result in a 20% decline in production during the coming years [4]. Since adaptability to drought varies considerably among species and varieties [5], the question of the choice of the appropriate coffee varieties and of the agricultural practices that should be used are of key importance in this country.

Composts, and especially vermicompost (i.e. compost produced in presence of epigeic earthworms) are increasingly used in agriculture for recycling organic wastes and improving crop production, replenishing soil organic matter (OM) stocks and improving soil physical, chemical and biological properties [6-9]. For instance, recent studies carried out in Viet Nam with maize showed that the amendment of vermicompost improves soil fertility, carbon sequestration, soil biodiversity and increases plant biomass and yield, as well as plant resistance to water shortage in comparison with compost or only mineral fertilization [10-17].The results of these studies had confirmed the positive effects of vermicompost amendment on soil quality, microbial activity and plant growth, but highlighted some of its limitations too. One of the key outcomes of this study is the confirmation of the positive influence of vermicompost on plant growth, although this increase is not necessarily associated to an increase in plant yield. Therefore, the aim of this study was to determine if the utilization of compost and vermicompost can help increase coffee resistance to water deficiency and if this resistance to drought varies for different varieties and according to the quality of the compost. Our hypotheses were (i) that growing coffee plantlets in presence of organic matter increases their root growth and the ability of soil to hold water, which therefore improves plant resistance to water shortage, and (ii) that these effects are variety dependent and (iii) the most important in presence of vermicompost.

2. Materials and methods

2.1. Experimental set-up

The experiment was carried out for 11 months in a greenhouse where coffee plants (either the old Robusta M38 variety or the new TR9 variety with high disease and drought resistances, as selected by the Western Highlands Agriculture and Forestry Science Institute, or the common Arabica L variety) were planted into 1 L polythene pots. Plants were grown during the first 3 months in 1kg of soil collected in a nursery farm located Daklak province in the Central Highlands (12°39′17″N, 108°06′19″E), which is the largest coffee cultivation area in Vietnam. Soils were thoroughly mixed as the recommendation from the nursery farm with the amount 0.14 kg of organic amendment (compost or vermicompost produced from buffalo manure, properties also shown in Table 1, see [13] for the production process) or not (control) (n = 3 per treatment). Superphosphate $CaH_4P_2O_8$ (4.72 g) was applied once in all the pots at the beginning of the experiment. Chemical fertilizers (0.007g urea CH_4N_2O and 0.003g pot $^{-1}$ potassium chlorite KCl) were also applied once a month. After 3 months, plants and soils were transferred into 3 L polyethylene pots containing 2 kg of soil from the field. In this area, the soil is a red basaltic Ferralsol. No fertilizers were applied after the transplanting of the plants. The soil moisture content during the trial was adjusted manually every week to 60-70% by controlling soil moisture content with Xiaomi soil moisture sensors and then water volume was done on a weekly interval (0.2 L of water each time) during the first 7 months of the experiment. The last month (8th month of experiment) plants received gradual decreasing water volume (0.2; 0.15; 0.1; 0.05 L) in two weeks and then no water was given to plants [30]. During the experiment, air humidity was always low, between 45 to 50%, and daily temperature was ~32 ˚C in average.

2.2 Plant and soil analyses

Plant height (in cm) and above-ground plant biomass (in kg pot^{-1}) were measured at the end of the experiment after drying in an oven at 50 ˚C for 10 days. Below-ground biomass was measured in differentiating the total root biomass in the soil from the nursery farm (inner sample) and in the transplanted 2L pot that contained only the poor quality soil from the field (outer sample). The root: shoot ratio was calculated in considering the overall root biomass. The color of leaves was observed by naked eyes as an indicator of plant resistance to drought and the day that leaves were all senescent was recorded and used as indicator of plant resistance to drought.

The chemical properties of the inner soil samples were analyzed for Total Organic Carbon (OC) content using the Walkey-Black method and total N, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$ contents were determined using Kjeldahl methods. Soil pH was measured in water (1:2). Total K and P contents were determined after extraction with H_2SO_4 and $HClO_4$ using a Flame photometer (TCVN 4053-81) and the amount of available P using Bray and Kurtz method (TCVN 8942-2011). Small cores (28 cm^3) were sampled in the inner soil samples for measuring field water-holding capacity and wilting points at pF = 2.5 and 4.2, respectively. Plant available water content (AWC) was calculated from the difference between the moisture contents of the water-holding capacity and wilting points. The properties of the soil from the nursery farm and from the field are also shown in Table 1.

Table 1 Chemical properties of soils, compost and vermicompost amendments at the beginning of the experiment. Variables are: pH_{H2O}, OC, N, total K and P (*P_2O_5, K_2O*), available N "*N-NO_3^- and N-NH_4*", available P and K (*P_a and K_a*).

Material	pH	OC (%)	N	P_2O_5	K_2O	N- NH_4^+ (mg kg^{-1})	N-NO_3^-	Pa	Ka
(a) Soil									
From nursery farm	4.2	3.2	0.2	0.2	0.3	26	30	224	149
From the field	4.6	0.7	0.1	0.1	0.1	12	13	55	59
(b) Organic amendments									
Compost	7.4	21.0	1.4	1.1	0.6	17	18	2618	5063
Vermicompost	7.1	17.6	1.8	1.7	0.8	22	26	3990	6074

2.3 Statistical analyses

A principal component analysis (PCA) was carried to assess differences between treatments from their soil properties and plant growth or resistance to water shortage. This analysis took place after the selection of the significant variables contributing to more than 6% of the overall contribution on the first and second axis of the PCA. Differences between treatments were also measured using two-way ANOVA, with fertilization and coffee variety as factors, and after verification of residual normality using the Shapiro-Wilk test and homogeneity of variances. Comparisons between means were carried out using the LSD test. All statistical calculations were carried out using R studio [18] and ade4, FactoMineR and Factoextra packages. Differences among treatments were declared significant at the P <0.05 probability level.

3. Results and discussion

Results of the PCA differentiating plant varieties according to the fertilization types are shown in Figure 1 and the data used for carrying out the PCA are shown in Table 2 and Table 3. In the Figure 1, PCA shows that plant varieties were clearly differentiated along the first and second axes of the PCA, which explained 54.2 and 25.4% of the total variability, respectively. In general, soils amended with organic matter were characterized by greater soil fertility (i.e. more important C, N, P, and K, N-NH_4^+, N-NO_3^- contents and higher soil pH) and allowed greater plant growth (i.e., plant height and above-ground biomass) in comparison with soils that received only chemical fertilizers (control). Root biomass within the inner and outer soil samples, AWC and K content in soils were not considered in the PCA analysis because they did not significantly contribute to the first and second dimensions of the PCA (P > 0.05 in all case). However, overlap between composted and vermicomposted plants for Robusta M38 and TR9 varieties. These results show that compost and vermicompost substrates similarly influenced soil and plant properties, despite the fact that vermicompost provided more nutrients to soil and plants than compost.

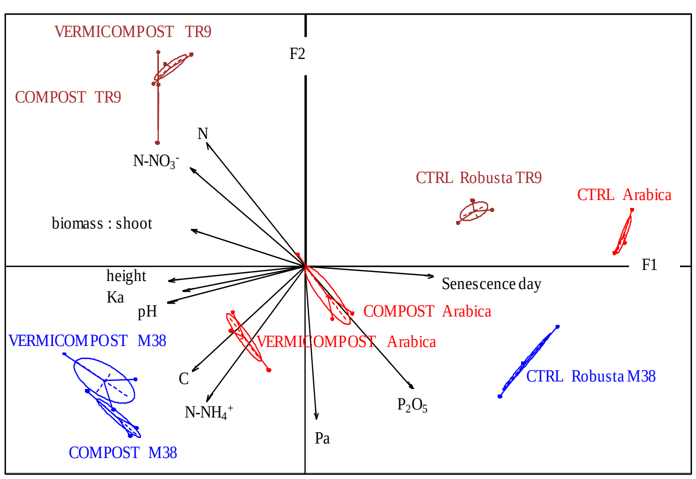

Figure 1 Projections of the samples (Arabica, Robusta M38 and TR39) plants amended mineral as control "*CTRL*" or mineral plus compost or vermicompost amendment (n = 3 per treatment) on the first (F1) and second (F2) principal components.

Contributions of the soil properties indicated by concentration in organic total C, N, P and K; available "*N-NH*$_4^+$ *and N-NO*$_3^-$"; and available K, P "*Ka and Pa*" and dried plant above-ground biomass, height and senescence day on F1 and F2 are indicated by the arrows.

Conversely, the utilization of vermicompost increased plant above-ground biomass, C, P and NH_4^+ contents but reduced the concentration in total P and K in soil in comparison with compost (Table 2).

Table 2 Influence of the variety (Arabica and M38 or TR9 Robusta) and organic amendment forms (compost, vermicompost) on the soil chemical of the inner soil samples.

Variety	Fertilization	pH	OC	N	P_2O_5	K_2O	Pa	Ka	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$
			(%)				(mg kg^{-1})			
Arabica	M	4.7 ^{D}	1.7 ^{C}	0.1 ^{C}	0.3 ^{B}	0.01 ^{B}	347 ^{A}	115 ^{E}	22.2 ^{D}	2.4 ^{D}
		(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.3)	(0.5)	(0.2)	(0.0)
	MC	5.2 ^{C}	2.3 ^{B}	0.1 ^{BC}	0.2 ^{C}	0.01 ^{B}	318 ^{C}	324 ^{A}	24.5 ^{CD}	4.0 ^{B}
		(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.4)	(0.9)	(0.1)	(0.0)
	MV	5.2 ^{C}	2.8 ^{A}	0.2 ^{B}	0.3 ^{B}	0.01^B	302 ^{C}	270 ^{C}	24.2 ^{CD}	4.8 ^{A}
		0.1	0.1	(0.0)	(0.0)	(0.0)	0.4	0.8	0.1	(0.0)
Robusta M38	M	4.8 ^{D}	2.1 ^{B}	0.1 ^{C}	0.4 ^{A}	0.01 ^{B}	357 ^{A}	102 ^{EF}	22.4 ^{D}	4.0 ^{B}
		(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.6)	(0.3)	(0.1)	(0.0)
	MC	5.5 ^{AB}	2.8 ^{A}	0.1 ^{BC}	0.3 ^{A}	0.01 ^{B}	298 ^{C}	330 ^{A}	30.0 ^{B}	6.0 ^{A}
		(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.9)	(0.3)	(0.1)	(0.0)
	MV	5.6 ^{A}	2.6 ^{A}	0.1 ^{B}	0.4 ^{A}	0.01 ^{B}	303 ^{C}	263 ^{CD}	30.0 ^{B}	6.0 ^{A}
		(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.3)	(0.6)	(0.1)	(0.0)
Robusta TR9	M	4.8 ^{D}	1.7 ^{C}	0.1 ^{C}	0.3 ^{B}	0.01 ^{B}	305 ^{BC}	87 ^{F}	26.2 ^{C}	4.0 ^{C}
		(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.3)	(0.5)	(0.1)	(0.0)
	MC	5.3 ^{BC}	2.3 ^{B}	0.2 ^{A}	0.2 ^{C}	0.01 ^{A}	251 ^{D}	287 ^{B}	32.8 ^{A}	3.0 ^{C}
		(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.5)	(0.5)	(0.1)	(0.0)
	MV	5.3 ^{BC}	2.1 ^{B}	0.2 ^{A}	0.2 ^{C}	0.01 ^{B}	254 ^{D}	246 ^{D}	33.6 ^{A}	3.0 ^{C}
		(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.5)	(0.6)	(0.1)	(0.0)

Treatments are represented as follow: "M" only NPK, "*MC*" NPK + compost and "*MV*" NPK + vermicompost. Variables are: pH_{H2O}, organic carbon OC, N, total K and P "*P_2O_5, K_2O*", available N "*N-NO*$_3^-$ *and N-NH*$_4$", available P and K "P_a *and* K_a". Upper case different letters within each coffee variety indicate significant differences between fertilizers (P<0.05). Values in parenthesis are standard errors, n = 3.

The positive influence of compost or vermicompost on plant height and above-ground biomass (Table 3) was more significant for Arabica and Robusta M38 (+111 and 105% for plant height and +170 and 143% for above-ground biomass, respectively for Arabica and Robusta M38) than for Robusta TR9 (+34% and +88% for plant height and above-ground biomass, respectively).

Table 3 Influence of the coffee variety Arabica, Robusta M38 or TR9 on coffee height (in cm), above- and below-ground biomass (in g, dried shoots, roots were differentiated into those sampled into the first patch that received compost substrates "*inner*" or those collected outside the patch in the poor quality soil "*outer*") and number of day needed for obtaining the senescence of leaves.

Variety	Fertilization	Height (cm)	Dried shoot (g)	Dried roots (g) (inner)	Dried roots (g) (outer)	Number of days (day)
Arabica	M	15.8 ^{C} (0.9)	1.7 ^{G} (0.1)	7.7 ^{A} (0.5)	6.8 ^{B} (0.1)	15 ^{A} (0.0)
	MC	32.5 ^{A} (1.8)	2.0 ^{G} (0.0)	8.4 ^{A} (0.4)	7.7^{A} (0.3)	12 ^{B} (0.0)
	MV	34.3 ^{A} (0.8)	5.0 ^{D} (0.1)	8.3 ^{A} (0.3)	7.6^{A} (0.1)	12 ^{B} (0.0)
Robusta M38	M	18.2 ^{C} (0.8)	3.3 ^{F} (0.1)	3.6 ^{E} (0.4)	7.7 ^{A} (0.5)	12 ^{B} (0.0)
	MC	35.4 ^{A} (1.5)	4.9 ^{D} (0.1)	4.8 ^{BCD} (0.1)	8.4 ^{A} (0.4)	6 ^{D} (0.0)
	MV	35.5 ^{A} (1.4)	8.9 ^{A} (0.1)	5.1^{BC} (0.1)	8.3 ^{A} (0.3)	6 ^{D} (0.0)
Robusta TR9	M	25.0 ^{B} (1.7)	3.9 ^{E} (0.3)	4.1 ^{DE} (0.1)	7.7 ^{A} (0.0)	12 ^{B} (0.0)
	MC	32.8 ^{A} (1.6)	6.0 ^{C} (0.0)	5.4 ^{B} (0.4)	7.9 ^{A} (0.1)	6 ^{D} (0.0)
	MV	32.0 ^{A} (1.9)	8.2 ^{B} (0.1)	4.3 ^{CDE} (0.5)	8.3 ^{A} (0.3)	8 ^{C} (1.0)

Treatments are represented as follow: "*M*" only NPK; "*MC*" NPK + compost and "*MV*" NPK + vermicompost. Upper case different letter within each coffee variety indicate significant differences between fertilizers ($P<0.05$). Values in parenthesis are standard errors, n = 3.

Therefore, this study confirmed the effectiveness of organic fertilization for improving coffee development, and also highlighted that this effect was more significant for Arabica and the old M38 Robusta variety compared to the new TR9 one. However, this study did not confirm the general assumption that vermicompost is more effective than aerobic compost for improving plant growth and yield and mitigating plant stresses [19-22]. Conversely, these results show that the positive effect of vermicompost on plant growth and yield is dependent on a large number of environmental factors, including crop varieties and soil properties [10,23,24]. Figure 1 also shows that plant resistance to drought was related to the first axis of the PCA.

Arabica plants resisted better to drought than Robusta varieties, without difference between TR9 and M38 Robusta varieties. This result was surprising since Robusta plants are known to be more productive, vigorous and robust than Arabica plants [25]. The root systems among the Robusta drought tolerance clones were associated by a deeper root length and a larger root dry mass for plant water consuming under the open directly light [26]. Plant resistance to drought under greenhouse condition was not associated to the root biomass and AWC, rejecting therefore our first hypothesis. Hence, plants that were only amended with chemical fertilizers showed a slower growth but resisted longer to drought, which did not confirm our first hypothesis (i.e. higher soil fertility is associated to greater plant growth and resistance to drought).

Finally, the influence of compost and vermicompost on root development was highly variable and did not influenced or influenced negatively the root: shoot ratio (Figure 2), then reducing plants resistance to drought [27,28].

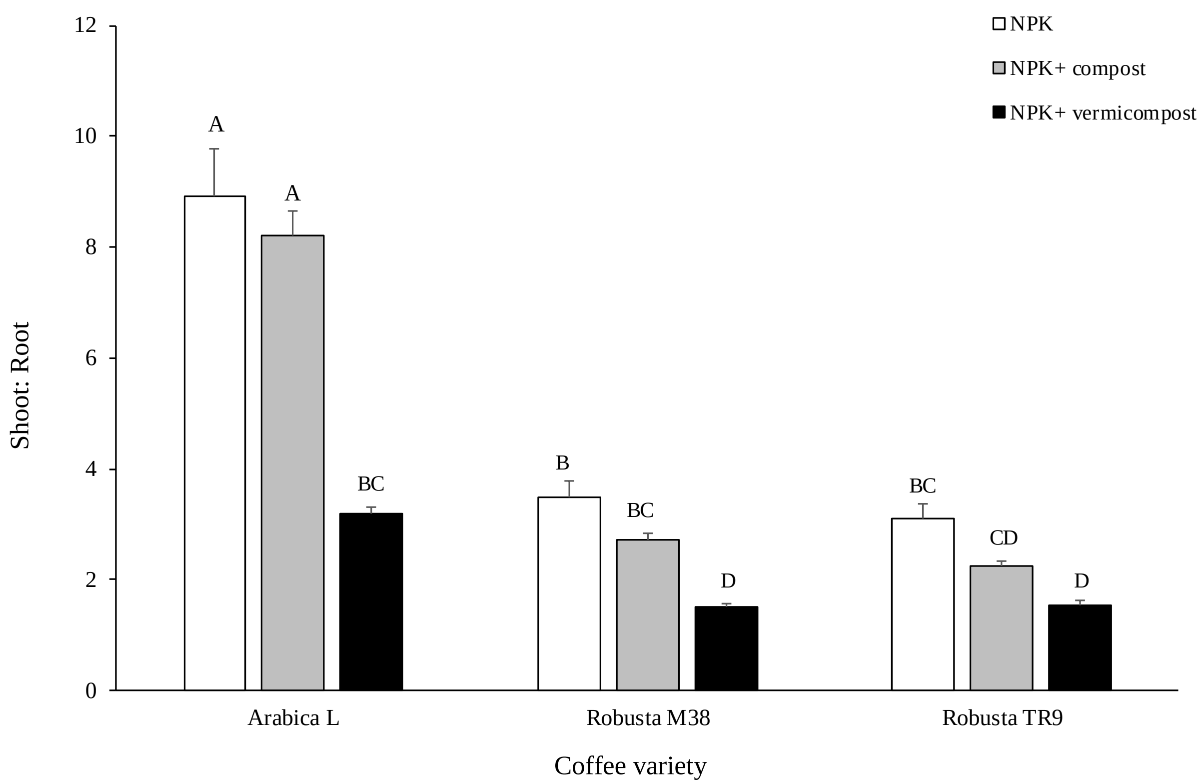

Figure 2 Root: shoot ratio for the different coffee varieties "*Arabica L, Robusta M38 and Robusta TR9*" amended with NPK+compost (in grey), NPK+ vermicompost (in black) or only NPK (in white). Histograms with the same letters are similar with $P > 0.05$. Bars are standard errors, n = 3.

These results are in contradiction with those of e.g. [29,30] who observed a better resistance of plants to water stress in presence of vermicompost. Consequently, the results of this study suggest that the resistance of coffee plantlets to drought is reduced if the nursery growing media contains compost or vermicompost. Although compost and vermicompost increased the development of coffee plantlets, especially with Arabica and the old variety Robusta M38, a key conclusion of this study is also that a too rapid growth of the above-ground biomass is likely to be associated with a more important sensitivity of coffee plantlets to drought in natural conditions, and most likely because of a higher allocation of energy towards the above-ground biomass at the expense of the below-ground biomass.

4. Conclusion

In conclusion, under the limits condition of the pot culture, the responses of coffee varieties to drought stress were presented by reduction in growth rate of plant height and total dry matter. Although further studies are needed to confirm the results of this study in the field, a recommendation from this study would be not to use compost or vermicompost in the nursery growing media but to apply organic matter at a later stage once the root system has developed enough.

5. Acknowledgments

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6. References

[1] Topik S. The integration of the world coffee market. In: Clarence SW, Topik S, editors. The Global Coffee Economy in Africa, Asia and Latin America, 1500-1989. 1st ed. Cambridge: Cambridge University Press; 2003. p. 21-49.

[2] Déchamp E, Breitler JC, Leroy T, Etienne H. Coffee (*Coffea arabica* L.) Methods Mol Biol. 2015; 1224: 275-291.

[3] Vu MT, Raghavan SV, Pham DM, Liong SY. Investigating drought over the central highland, Vietnam, using regional climate models. J Hydrol. 2015;526:265-273.

[4] VnExpress International [Internet]. Hanoi: The Corporation; c1997 [cited 2016 Dec31]. Vietnam coffee exports grew in 2016 despite drought. Available from: https://e.vnexpress.net/news/business/vietnam-coffee-exports-grew-in-2016-despite-drought-3522008.html.

[5] Cai ZQ, Chen YJ, Guo YH, Cao KF. Responses of two field-grown coffee species to drought and re-hydratation. Photosynthetica. 2005;43(2):187-193.

[6] Hargreaves JC, Adl MS, Warman PR. A review of the use of composted municipal solid waste in agriculture. Agric Ecosyst Environ. 2008;123(1-3):1-14.

[7] Arthur E, Cornelis WM, Vermang J, De Rocker E. Amending loamy sand with three compost types: impact on soil quality. Soil Use Manage. 2011;27(1):116-123.

[8] Domínguez J, Brandón GM. The influence of earthworms on nutrient dynamics during the process of vermicomposting. Waste Manag Res. 2013;31(8):859-868.

[9] Thangasamy A, Gorrepati K, Ahammed TPS, Savalekar RK, Banerjee K, Sanker V, et al. Comparison of organic and conventional farming for onion yield, biochemical quality, soil organic carbon, and microbial population. Arch Agron Soil Sci. 2018;64(2):219-230.

[10] Doan TT, Ngo TP, Rumpel C, Nguyen VB, Jouquet P. Interaction between compost, vermicompost and earthworm activity. A one year greenhouse experiment. Sci Hortic. 2013;160:148-154.

[11] Doan TT, Jusselme MD, Lata JC, Nguyen VB, Jouquet P. The earthworm species *Metaphire posthuma* modulates the effect of organic amendments (compost vs. vermicompost from buffalo manure) on soil microbial properties. Eur Journal Soil Biol. 2013;59:15-21.

[12] Doan TT, Bouvier C, Bettarel Y, Bouvier T, Tureaux TH, Janeau JL, et al. Influence of buffalo manure, compost, vermicompost and biochar amendments on bacterial and viral communities in soil and adjacent aquatic systems. Appl Soil Ecol. 2014;73(1):78-86.

[13] Doan TT, Tureaux HT, Janeau JL, Rumpel C, Jouquet P. Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in Northern Vietnam; a three years experiment in mesocosms. Sci Total Environ. 2015;514:147-154.

[14] Ngo TP, Rumpel C, Doan TT, Jouquet P. The effect of earthworms on carbon storage and soil organic matter composition in tropical soil amended with compost and vermicompost. Soil Biol Biochem. 2012;50:214-220.

[15] Ngo TP, Rumpel C, Ngo QA, Alexis M, Vargas GV, Maria LMG, et al. Biological and chemical reactivity and phosphorus forms of buffalo manure compost, vermicompost and their mixture with biochar. Bioresour Technol. 2013;148:401-407.

[16] Ngo TP, Rumpel C, Doan TT, Tureaux HT, Dang DK, Jouquet P. Use of organic substrates for increasing soil organic matter quality and carbon sequestration of tropical degraded soil: a 3-year mesocosms experiment. Carbon Manag. 2014;5(2):155-168.

[17] Jouquet P, Doan TT. The utilization of vermicompost reduces the invasiveness of the earthworm species Dichogaster bolaui in a degraded tropical soil in Northern Vietnam. Eur J Soil Biol. 2014;64:46-52.

[18] The R Foundation [Internet]. Vienna: R Development Core Team; c2010. [cited 2020 Jan 20]. Download and install R. Available from: http://mirrors.psu.ac.th/pub/cran/.

[19] Pramanik KP, Ghosh GK, Ghosal PK, Bani KP. Changes in organic –C, N, P and K and enzyme activities in vermicompost of bio degradable grganic wastes underl and microbial inoculants. Bioresour Technol. 2007;98(13):2485-2494.

[20] Gonzalez M, Gomez E, Comese R, Quesada M, Conti M. Influence of organic amendments on soil quality potential indicators in an urban horticultural system. Bioresour Technol. 2010;101(22):8897-8901.

[21] Lazcano C, Dominguez J. The use of vermicompost in sustainable agriculture: impact on plant growth and soil fertility. Soil Nutr. 2011;10:1-23.

[22] Arani AB, Sanavy SA, Masood A, Bidgoli AM. Towards improving the agronomic performance, chlorophyll fluorescence parameters and pigments in fenugreek using zeolite and vermicompost under deficit water stress. Ind Crops Prod. 2017;109:346-357.

[23] Jouquet P, Plumere T, Doan TT, Rumpel C, Duc TT, Orange D. The rehabilitation of tropical soils using compost and vermicompost is affected by the presence of endogeic earthworms. Appl Soil Ecol. 2010;46(1): 125-133.

[24] Lazcano C, Revilla P, Malvar RA, Dominguez J. Yield and fruit quality of four sweet corn hybrids (*Zea mays*) under conventional and integrated fertilization with vermicompost. J Sci Food Agric. 2011;91(7):1244-1253.

[25] Cheserek JJ, Gichimu BM. Drought and heat tolerance in coffee: a review. Int J Agric Res Soil Sci. 2012;2(12):498-501.

[26] Ramos LC, Carvalho A. Shoot and root evaluations on seedlings from coffea genotypes. Bragantia. 1997; 56(1):59-68.

[27] Kozlowski TT, Pallardy SG. Acclimation and adaptive responses of woody plants to environmental stresses. Bot Rev. 2002;68(2):270-334.

[28] Brunner I, Herzog C, Dawes MA, Arend M, Sperisen C. How tree roots respond to drought. Front Plant Sci. 2015;6:547.

[29] Benitez AG, Valdivia CB, Rivera RC, Avila JP, Crespo EC, Velazque AN. Vermicompost and water stress effects on dry beans (*Phaseolus vulgaris* L.): productive parameters and water relations. Phyton Int J Exp Bot. 2017;86(1):28-39.

[30] Hosseinzadeh SR, Amiri H, Ismaili A. Nutrition and biochemical responses of chickpea (*Cicer Arietinum* L.) to vermicompost fertilizer and water deficit stress. J Plant Nutr. 2017;40(16):2259-2268.