International Scholars Journals

African Journal of Wood Science and Forestry ISSN 2375-0979 Vol. 8 (2), pp. 001-008, February, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Effect of polyethylene mulching on the spatial variability of soil physical properties and growth parameters of taro (*COLOCASIA ESCULANTUM*)

Nsalambi V. Nkongolo[1]*, Mitate Yamada[2] and Izumi Nakagawa

[1]Department of Agriculture and Environmental Science, College of Agricultural and Natural Sciences, Lincoln University, Jefferson City, MO 65102-0029, U.S.A.

[2]Crop Production and Postharvest Technology Division, Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba Science City, Japan 305-8686.

[3]Vegetable Cultivation Technology System Laboratory, Department of Farmland Utilization, National Agriculture Research Center, Tsukuba, Ibaraki 305-8666, Japan.

Accepted 16 November, 2019

The objective of this study was to investigate the spatial variability of soil physical properties and growth of taro (*COLOCASIA ESCULANTUM*) in an unfertilized 42 m ridge covered with black plastic mulch. The study was conducted at the National Agriculture Research Centre Tsukuba (Japan). The experimental field was made of 3 adjacent ridges of 42 m long and 0.90 m width each. Uniform taro corms were planted in the middle of each ridge at 0.30 m spacing. At the end of growing season, soil samples were taken for measurements of air content ($\square_a$), bulk density (ρ_b), gravimetric (θ_g) and volumetric water contents (θ_v), total pore space (TPS), pore tortuosity (τ), gas diffusion coefficient ($D_S D_O$) and water-filled pore space (WFPS). Taro plants were harvested, separated into leaves (LFW), petioles (PFW), corms (CFW), roots (RFW) and tubers (TFW). All autocorrelation functions (r(*H*)) for soil properties and taro growth dropped sharply after one lag. Except for θ_g, (r(*H*)) for θ_a, ρ_b, Ds/Do and WFPS dropped below zero at about 16 lags, which revealed that these soil properties could be sampled at 4.8 m for independent observations. For taro growth parameters, only PFW, TFW and RFW could be sampled together at 14 lags or 4.2 m for uncorrelated observations. Except for RFW, all taro growth parameters significantly correlated among themselves and with θ_g, $\square_a$, ρ_b, Ds/Do, WFPS and τ with correlation coefficients ranging from 0.16 to 0.99. Plastic mulch improved soil properties which in turn improved the relationship between these properties and taro growth parameters.

Key words: Soil physical properties, taro growth parameters, plastic mulch, volcanic ash soil.

INTRODUCTION

Taro (*Colocasia esculantum*) is an herbaceous, perennial, tropical root crop composed of a main plant and suckers. It is one of the most important staple crops in the Pacific Islands (Ctahr and Taro, 2009) but also widely grown throughout Africa, Asia, West Indies and South America. It is harvested primarily for its corm, which is a starchy, underground stem. Taro is adapted to moist envi-ronments and can be grown under rain-fed or irrigated upland (that is, non flooded) as well as flooded conditions (Miyasaka et al., 2003). Taro requires deep planting for optimum corm set, because shallow soils provide a restrictive environment for corm and root development. In addition, Taro has important water requirements, which are not always met by soil moisture. In upland taro cultivation, the ability of a soil to store water becomes an important issue due to the high variability and unpre-dictability of rainfall and the cost of irrigation. Therefore, cultural practices, like mulching with black polyethylene are necessary to mitigate the impact of limited moisture. The use of plastic materials for mulching is a very com-mon practice for vegetable crops and black polyethylene

*Corresponding author. E-mail: nkongolo@lincolnu.edu. Tel: +1 (573) 681-5397. Fax: +1 (573) 681-5154.

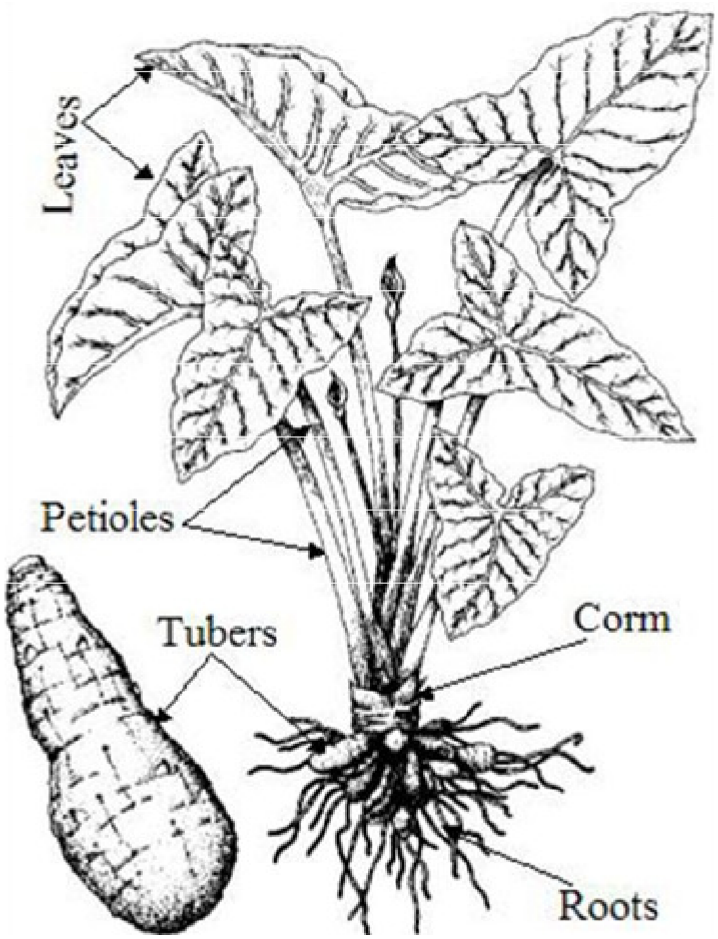

Figure 1. Taro plant morphology.

is widely used due to its excellent properties and low cost (Moreno and Moreno, 2008). In fact, plastic mulches have many positive advantages for the user, such as increased yields, earlier maturing of crops, crops of higher quality, enhanced insect/ pest management, and weed control. Furthermore, black polyethylene cover-sheets increases soil moisture retention, soil tempera-ture, reduces evapo-transpiration from the soil and enhance crop yield. The effect of black polyethylene on soil properties and crop yield has been investigated by severalworkers (Miyasaka et al., 2001; Moreno and Moreno, 2008; Oñate and Peco, 2005; van der Meulen et al., 2006; Hulugalle et al., 1990; Anikwe et al., 2007; Ossom and Matsenjwa, 2007; Chaudhry et al., 2008; Singh et al., 2008; Subrahmaniyan et al., 2008; Ndubuisi, 2009; Takashi and Hajime, 2000; Subrahmaniyan et al., 2006; Islam et al., 2007; Isalam et al., 2006). However, it is still unclear how the use of black polyethylene as a mulching technique affects the spatial variability of soil properties and in-turn, how this variability in soil proper-ties relate to plant growth parameters. The objective of this study was to investigate the spatial variability of soil physical properties and the corresponding variability in taro growth parameters on a volcanic ash covered with black polyethylene.

MATERIALS AND METHODS

Soil preparation and taro management

This study was conducted at the National Agriculture Research Center, Tsukuba, Japan. The soil of the experimental site is a light-colored Kuroboku soil (Low-humic Andosols) originating from volcanic ash. The experiment was composed of three adjacent ridges of 42 m long and 0.90 m width. Soil preparation includes mowing and subsoiling to a depth of 0.20 - 0.30 m with a regular size Shibuya D-23 tractor attached with a Rotary Cx 1402 cultivator. No plowing was done. Three parallel ridges of 42 m long and 0.90 m large crossing all the field were made. Each of the 42 m ridge was planted with taro at 0.30 m spacing and covered with a black plastic mulch and One hundred thirty nine samples of each soil and taro plant were collected along one of the three 42 m ridges at the above mentioned spacing. Soil samples were taken with a 0.05 m diameter and 0.05 m height cylinder while the entire taro plant at each soil sampling location was harvested, cleaned, separated into leaves, petioles, corms, roots, tubers (Figure 1) and fresh weight was recorded. Fresh wet weight of soil was also recorded and transferred into a three phase meter (Daiki) for soil and air volume determination. They were oven dried at 105°C for 24 h and the

Table 1. Summary of simple statistics for soil physical properties

Simple statistics	$\square_a$(m^3 m^{-3})	ρ_b(kg.m^{-3})	θ_g(kg.kg^{-1})	θ_v(m^3 m^{-3})	TPS(m^3 m^{-3})	τ(m m^{-1})	D_SD_O(m^2 s^{-1}/ m^{-2} s)	WFPS(m^3 m^{-3})
Mean	0.48	0.59	0.50	0.30	0.78	2.08	0.23	38.09
SD	0.03	0.03	0.02	0.02	0.01	0.12	0.02	2.67
C.V.	5.27	4.30	4.58	6.07	1.31	5.61	10.48	7.02
Minimum	0.38	0.54	0.43	0.26	0.74	1.89	0.14	32.91
Median	0.49	0.59	0.50	0.29	0.78	2.04	0.24	37.66
Maximum	0.53	0.68	0.57	0.37	0.80	2.63	0.28	49.33
Skew	-0.93	0.95	0.68	1.01	-0.98	1.45	-0.71	1.07
Kurtosis	1.66	1.15	0.74	1.65	1.38	3.70	0.94	2.00

$\square_a$ = air content (air content), ρ_b = bulk density, θ_g = gravimetric water content, θ_v = volumetric water content, TPS = total pore space, τ = pore tortuosity, D_SD_O = relative gas diffusion coefficient, WFPS = water-filled pore space.

volume of dry soil was recorded by three phase meter. Soil bulk density, total pore space, gravimetric water content, volumetric water content and air filled porosity were calculated as described by Nkongolo et al. (2007a)

RESULTS AND DISCUSSION

Soil physical properties

During the time of sampling, 62% of the pore space of volcanic ash soil was occupied by air as revealed by an air-filled porosity (0.48 $m^3 m^{-3}$) while 38% of the pore space was filled with water (Table 1). Values for soil air and total porosity in volcanic ash soil were higher as compared to regular mineral soil. These results were in agreement with other authors who have suggested that the volcanic ash soils exhibit unique soil properties such as high water retention, large total porosity due to noncrystalline materials like allophane and good drainage, all of which are favorable for plant root growth (Shoji et al., 1993; Moldrup et al., 2003). The bulk density was very low (0.59 kg m^{-3}) as expected for volcanic ash soils. In fact, as suggested earlier for soil air content and total pore space, the low bulk density of volcanic ash soils is also due to high porosity caused by well-developed aggregate structures made of non crystalline minerals (Nanzyo et al., 2001; Shoji et al., 1993). The coefficient of variation (CV) varied between 1.31 to 10.48% and was confined within the range of normally reported for soil physical properties. The highest CV value was recorded for the relative gas diffusion coefficient (10.34%), followed by water filled pore space (7.02%). The pore tortuosity factor was also low as the result of well-developed aggregate structures for this type of soil (Nanzyo et al., 2001; Hamamoto et al., 2008). All means for soil physical properties were equal or closer to their corresponding medians, suggesting that the data was normally distributed. This is also confirmed by low CV, kurtosis and skew values.

Taro growth

The total weight of taro plant varied from 508 to 15816 g on a fresh weight basis. Corm fresh weight ranged from 30 to 1020 g with an average of 347.84 g/plant (Table 2). Assuming a plant spacing of 30 × 30 cm in a regular field for taro, each plant would have occupied an area of roughly 900 cm^2. In addition, considering the fact that taro corm contains 63 to 85% of water (Huang et al., 2007; Onwueme, 1999, 1994), taro's assumed corm yield was therefore ranged between 5.86 and 14.30 ton/ha (on dry matter basis) with an average yield of 9.66 ton/ha. These value fall within the range of taro yield reported in Japan, but short below the yields of taro in China, Salmon Islands and Fiji (Onwueme, 1999). However, this assumed yield was obtained without fertilizer input, only as the results of soil physical properties and other growth parameters improvement by the use of black polyethylene mulch. Our results agree with those reported by nikwe et al. (2007) who studied tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (*Colocasia esculenta*) on an ultisol in Southeastern Nigeria. They reported that the highest corm yield in tilled black plastic mulched plots, and concluded that the plastic mulched plots had provided a better soil environment for cocoyam than un-mulched plots and in tilled mulched plots, especially tilled black plastic mulched plots provide superior edaphic environment for cocoyam when compared to other

Table 2. Summary of simple statistics for Taro's growth parameters.

Simple statistics	LFW ($g.plant^{-1}$)	PFW ($g.plant^{-1}$)	CFW ($g.plant^{-1}$)	RFW ($g.plant^{-1}$)	TFW ($g.plant^{-1}$)	AGB ($g.plant^{-1}$)	BGB ($g.plant^{-1}$)	TTB ($g.plant^{-1}$)
Mean	234.68	791.37	347.84	288.20	888.78	1800.30	1521.60	3321.90
SD	21.44	690.98	214.57	57.94	575.55	1410.20	785.67	2038.20
C.V.	9.14	87.32	61.69	20.11	64.76	78.33	51.64	61.36
Minimum	203.00	10.00	30.00	198.00	20.00	204.00	282.00	508.00
Median	231.00	710.00	310.00	280.00	800.00	1639.00	1360.00	3066.00
Maximum	302.00	4760.00	1020.00	634.00	4340.00	9822.00	5994.00	15816.00
Skew	0.88	3.26	0.86	2.85	2.94	3.17	2.08	2.54
Kurtosis	0.61	15.16	0.58	14.84	15.44	14.55	9.23	11.61

LFW = leaves fresh weight, PFW = petioles fresh weight, CFW = corms fresh weight, RFW = roots fresh weight, TFW = tubers fresh weight, AGB = above ground biomass (leaves + petioles), BGB = below ground biomass, (corms + tubers + roots) and TTB = taro total biomass (AGB + BGB).

treatments used. Studying the influence of mulch on agronomic characteristics, soil properties, disease and insect pest infestation of dry bean (*Phaseolus vulgaris* L.) in Swaziland, Ossom and Matsenjwa (2007) reported that un-mulched plants and plant under black polyethylene mulch had significantly higher pod yield as compared to plants under grass, newspaper and clear plastic mulches. Better soil properties and higher plant yield in black polyethylene mulch treatment was reported by various workers (Singh et al., 2008; Subrahmaniyan et al., 2008; Ndubuisi, 2009). Chaudhry et al. (2008) studied mulching impact on moisture conservation, soil properties and plant growth. They observed maximum saving/ conservation of water (45%) and high plant growth under polyethylene sheet and concluded that polythene sheet is more efficient to reduce water losses, but it is a costly option.

Spatial variability of soil physical properties

The highest fluctuations in soil physical properties recorded between 36 and 41 m for air filled porosity, gas diffusion coefficient, gravimetric water content and water filled pore space, as showed by time series plots (Figure 2). Air filled porosity and gas diffusion coefficient decreased sharply as gravimetric water content and water filled pore space increased. However, soil bulk density increased sharply from 0.53 to about 0.67 kg/ m^3 between 18 and 24 m along the 42 m transect. Autocorrelation plots for air-filled porosity, gas diffusion coefficient, gravimetric water content and water filled pore space recorded similar patterns. The autocorrelation function (r(*h*) dropped quickly to less than unity after only one lag and continued to decrease without leveling off asthe lag and dropped below zero at about 16 lags for air-filled porosity, gas diffusion coefficient and water filled pore space. However, r(*h*) for gravimetric water content continued to decrease without dropping to zero. Physical systems which may exhibit such type of autocorrelogram include sediment deposits for periodic flooding or compacted non compacted patterns due to wheel traffic in a row crop (Warrick et al., 1986). In this study, the presence of compacted-non compacted patterns were due to use of tractor during field preparation might be one of the reasons. In addition, posing the plastic film mulch on the ridge might also have brought some compaction The autocorrelation function (r(*h*)) for soil bulk density recorded cyclic patterns It dropped to 0.22 after one lag, continued to drop, then leveled off to 0.22 after 11 lags or 3.3 m, and continued its up-low patterns. Given that when r(*h*) drops to 0 the samples are no longer were related to one another, air-filled porosity, bulk density, gas diffusion coefficient and water filled pore space could therefore be sampled together at 4.80-m or 16 lags for independent observations.

Spatial variability of taro's growth parameters

All taro growth parameters recorded two peak zones, first between 10 and 12 m and the second zone between 35 and 37 m of the 42 m transect (Figure 3). Between these two zones, the fresh weight of leaves, petioles, tubers, corms and roots fluctuated with a series of high and low values, but did not exceed the peak zones. Autocorrelation function (r(*h*)) for taro petioles, tubers and roots recorded similar cyclic patterns: they dropped after one lag and continued with high and low

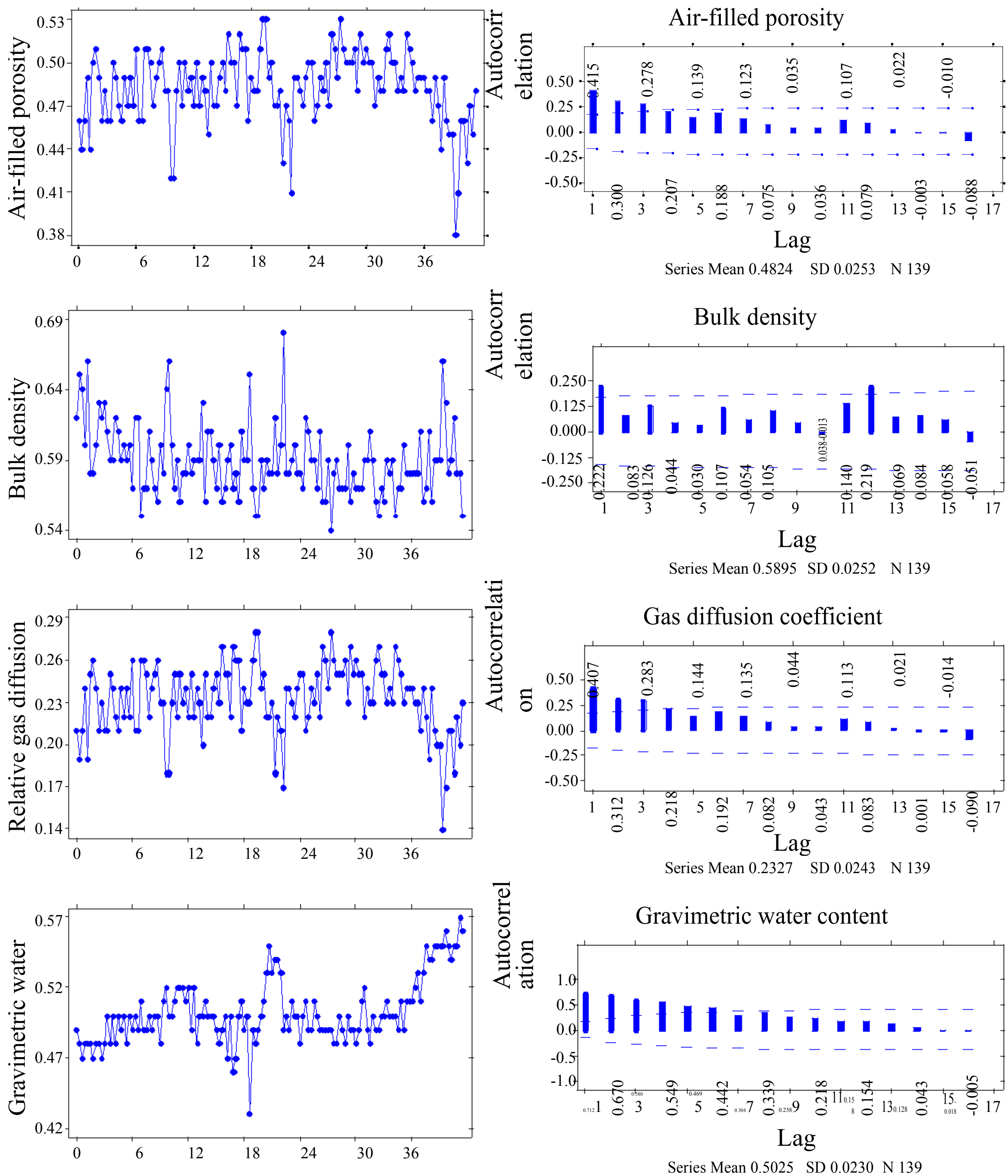

Figure 2. Time series and autocorrelation plots of soil physical properties.

values to finally drop below zero after 14 lags. Since the distance at which r(*h*) drops to 0 indicates the limiting distance in which samples are related to one another, taro petioles, tubers and roots could therefore be

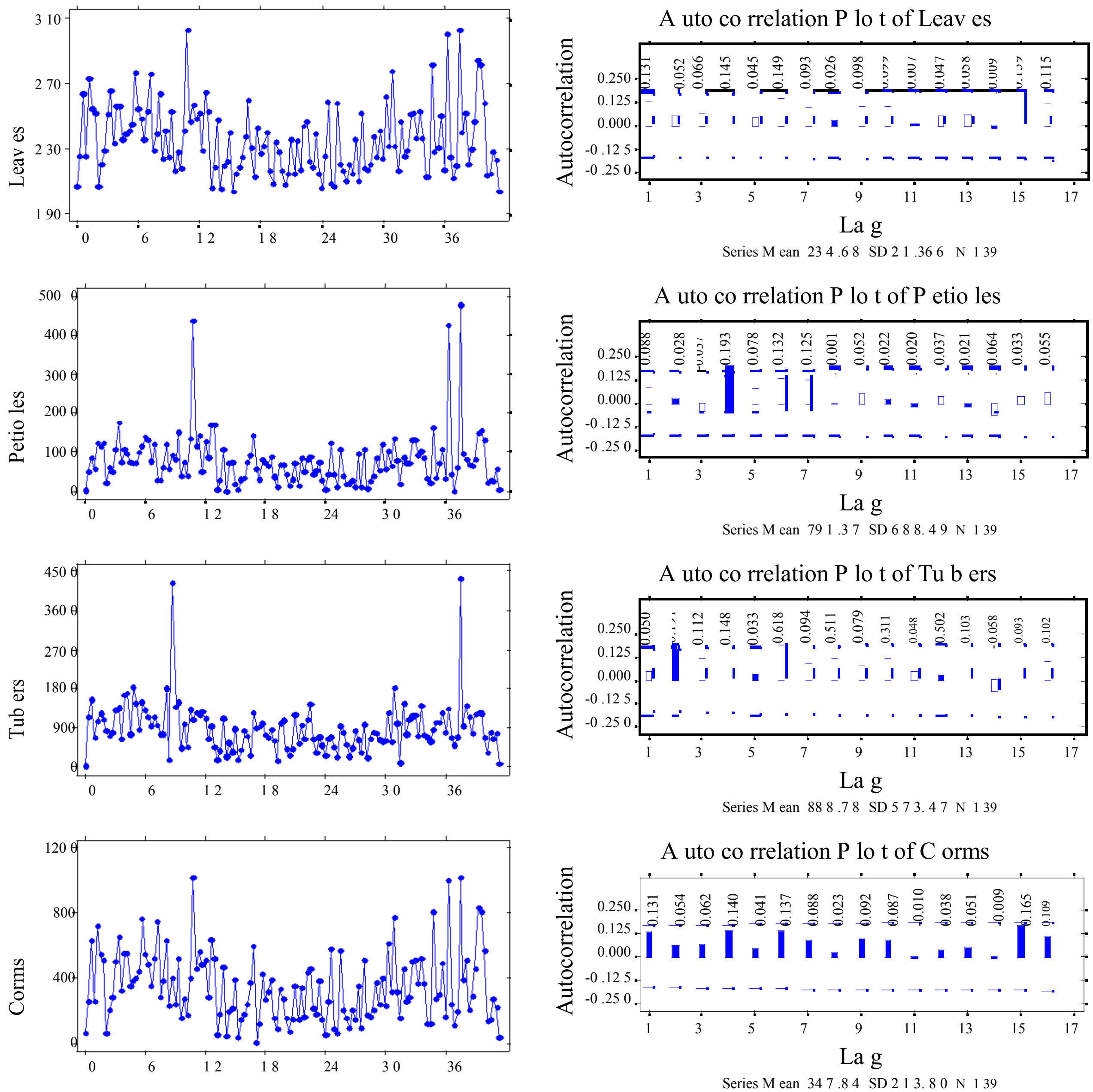

Figure 3. Times series and autocorrelation plots of taro growth parameters.

sampled together at 14 lags or 4.2 m for independent observations. Autocorrelation function (r(*h*)) for taro leaves and corms also showed cyclic patterns, but they shifted between high and low values without dropping to zero. As discussed above, physical systems which may exhibit such type of autocorrelogram include sediment deposits for periodic flooding or compacted non compacted patterns due to wheel traffic in a row crop (Warrick et al., 1986). Perhaps, compaction patterns caused by tractor during field preparation might have a direct impact on plant growth and therefore influenced the autocorrelogram.

Correlation between soil physical properties and taro growth parameters

Soil air filled porosity ($\square_a$) was significantly correlated with leaf fresh weight (LFW) (p = 0.0429) and corms fresh weight (CFW) (Table 3). Conflicting results have been reported for the relationships between soil air content and plant growth. Ouimet et al.(1990), Caron et al. (2001), Nkongolo et al. (2007b) have also not reported any relationship between $\square_a$ and plant growth. However, De Rouin et al. (1988) found a minimal relationship between $\square_a$ and plant growth. Wall and Heiskanen (2003) examined

Table 3. Correlation between soil physical properties and taro growth parameters.

	LFW	PFW	ABG	CFW	RFW	$\square_a$	θ_g	D_SD_O
PFW	0.822							
p-value	*0.0001*							
AGB	0.8385	0.9922						
p-value	*0.0001*	*0.0001*						
CFW	0.9982	0.8198	0.8371					
p-value	*0.0001*	*0.0001*	*0.0001*					
RFW	0.6217	0.5707	0.5803	0.6134				
p-value	*0.0001*	*0.0001*	*0.0001*	*0.0001*				
$\square_a$	-0.1720	-0.1234	-0.1144	-0.1664	-0.0603			
p-value	*0.0429*	0.1479	0.1800	*0.0503*	0.4806			
θ_g	0.1239	0.1734	0.1701	0.1166	0.1132	-0.4659		
p-value	0.1463	*0.0412*	*0.0453*	0.1715	0.1846	0.0001		
D_SD_O	-0.1686	-0.1243	-0.1146	-0.1629	-0.0600	0.998	-0.4713	
p-value	*0.0472*	0.1450	0.1790	*0.0554*	0.4829	0.0001	0.0001	
τ	0.1783	0.1201	0.1121	0.1731	0.0607	-0.995	0.4634	-0.9884
p-value	*0.0357*	0.1591	0.1889	*0.0416*	0.4781	0.0001	0.0001	0.0001

the effect of air-filled porosity and organic matter concentration of soil on growth of *Picea abies* seedlings after transplanting. They found that the shoot height and mass growth as well as root mass were significantly higher in 20, 30 and 40% than in 5 and 10% air-filled porosity. The air content in this study ranged from 0.38 to 0.48 $m^3\ m^{-3}$. Soil gravimetric water content was significantly correlated with plant fresh weight (PFW) ($p = 0.0412$) and above ground biomass (AGB) ($p = 0.0543$). Our results conflict with those reported by Bilderback and Lorscheider (1995) who studied the physical properties of double-processed pine bark on rooting of *Photinia* × *'fraseri'* cuttings and found that regression and correlation analyses indicated no relationship between percent volume of air space (air-filled porosity) or container capacity (water content) with rooting responses measured for any of the three species propagated. The relative gas diffusion coefficient (D_SD_O) significantly correlated with taro leaf fresh weight (LFW) ($p = 0.0472$) while the pore tortuosity factor (τ) significantly correlated with both LFW ($p = 0.0357$) and CFW $p = 0.0416$). These results agree with those reported in other studies. Caron et al. (2001) found that root growth of *Euphorbia pulcherima* was significantly and positively correlated to gas relative diffusivity. Similarly, the existence of correlations between plant growth and the exchange properties of media (pore tortuosity factor and gas diffusion coefficient) has been reported by Nkongolo et al. (2007c); Nkongolo and Caron (2006). Taro growth parameters were also significantly correlated among themselves and coefficients of correlation ranged between 0.58 to 0.99. Finally, soil physical properties also correlated among themselves with correlation coefficients ranging from 0.47 to 0.99.

REFERENCES

Anikwe MAN, Mbah CN, Ezeaku PI, Onyia VN (2007). Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (*Colocasia esculenta*) on an ultisol in southeastern Nigeria. Soil Tillage Res., 93(2): 264-272.

Bilderback TE, Lorscheider MR (1995). Physical properties of double-processed pine bark: Effects on rooting. Acta Hortic., 401:77-83.

Caron J, More PH, Rivière LM (2001). Aeration in growing media containing large particle size. Acta Hortic., 548: 229-234.

Chaudhry M R, Malik AA, Sidhu M (2008). Mulching Impact on Moisture Conservation, Soil Properties and Plant Growth. Pakistan J. Water Resourc., 8 (1): 1-8.

Ctahr, Taro (2009). Taro Research by the College of Tropical Agriculture and Human Resources. Background paper. University of Hawai at Manoa, HI. 40p.

De Rouin N, Caron J, Parent LE (1988). Influence of some artificial substrates on productivity and DRIS diagnosis in greenhouse tomatoes (lycopersicon esculentum L. Mill., cv ‘Vedettos’). Acta Hortic., 221: 45-52.

Hamamoto S, Tokida T, Miyazaki T, Mizoguchi M (2008). Dense gas flow in volcanic ash soil: Effect of pore structure on density-driven flow. Soil Sci. Soc. Am. J., 72(2): 480-486.

Huang CC, Chen WC, Wang CR (2007). Comparison of Taiwan paddyand upland-cultivated taro (*Colocasia esculenta* L.) cultivars for nutritive values. Food Chem., 102(1): 250-256.

Hulugalle NR, Lal R, Gichuru M (1990). Effect of Five Years of No-tillage and Mulch on Soil Properties and Tuber Yield of Cassava on an Acid Ultisol in South-eastern Nigeria. Exp. Agric., 26(2): 235-240.

Islam MJ, Hossain AKMM, Khanam F, Majumder UK, Rahman MM, Rahman MS (2007). Effect of mulching and fertilization on growth and yield of garlic at dinajpur in Bangladesh. Asian J. Plant Sci., 6(1): 98-101.

Islam MS, Karim AJMS, Hossain MS, Masud MM (2006). Tillage and mulch effects on some soil physical properties in shallow red brown terrace soils of Bangladesh. Bull. Inst. Trop. Agric. Kyushu Univ., 29(1): 69-82.

Miyasaka SC, Ogoshi RM, Tsuji GY, Kodani LS (2003). Site and Planting Date Effects on Taro Growth Comparison with Aroid Model Predictions. Agron. J., 95(3): 545-557.

Miyasaka SC, Hollyer JR, Kodani LS (2001). Mulch and compost effects on yield and corm rots of taro. Field Crops Res., 71(2): 101-112.

Moldrup P, Yoshikawa S, Olesen T, Komatsu T, Rolston DE (2003). Air permeability in undisturbed volcanic ash soils: Predictive model test and soil structure fingerprint. Soil Sci. Soc. Am. J., 67(1): 32-40.

Moreno MM, Moreno A (2008). Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. Sci. Hortic., 116(3): 256-263.

Nanzyo MH, Tsuzuki H, Otsuda H, Yamasaki S (2001). Origin of clay-size vermiculite in sandy volcanic ash soils derived from modern

Pinatubo Lahar deposits in central Luzon, Philippines. Clay Sci., 11(4): 381-390.

Ndubuisi MC (2009). Physical Properties of an Ultisol Under Plastic Film and No-Mulches and their Effect on the Yield of Maize. J. Am. Sci., 5(5): 25-30.

Nkongolo NV, Yamada M, Nakagawa I (2007a). Spatial variability selected soil physical properties and root growth of sweet corn. J. Environ. Mon. Rest. 3(1): 276-285.

Nkongolo NV, Yamada M, Yamasaki A (2007b). Effect of animal manure on the physical properties of a volcanic ash soil and cabbage growth response. J. Environ. Mon. Rest, 3(1): 304-313.

Nkongolo NV, Gauthier F, Caron J (2007c). Effects of fresh and composted organic wastes on media physical properties and growth of three ornamental species. Int. J. Soil Sci., 2(4) :235-246.

Nkongolo NV, Caron J (2006). Pore space organization and plant response in peat Substrates. I. Prinus x Cistena. Sci. Res. Essays, 1(3): 77-89

Onwueme IC (1999). Taro Cultivation in Asia and the Pacific. FAO Regional Office for Asia and the Pacific, RAP Publication No. 1999/16, Bangkok, Thailand.

Onwueme IC (1994). Tropical root and tuber crops - Production, perspectives and future prospects. FAO Plant Production & Protection Paper 126, FAO, Rome, 228p.

Oñate JJ, Peco B (2005). Policy impact on desertification: stakeholders' perceptions in southeast Spain. Land Use Pol., 22(2):103-114.

Ouimet R, Charbonneau J, Parent LE, Blain J, Gosselin A (1990). Effect of peat substrate composition and growing bags volume on the productivity of greenhouse tomato. Can J. Plant Sci., 70(2):585-590.

Ossom EM, Matsenjwa VN (2007). Influence of Mulch on Agronomic Characteristics, Soil Properties, Disease and Insect Pest Infestation on Dry Bean (*Phaseolus vulgaris*) in Swaziland. World J. Agric. Sci., 3(6): 696-703.

Singh AK, Singh S, Appa Rao VV, Meshram DT (2008). Effect of mulching on soil properties, growth and yield of 'NA7' aonla (Emblica officinalis) in semi-arid ecosystem. Indian J. Agric. Sci., 78(2): 193-197.

Shoji S, Nanzyo M, Dahlgren R (1993). Volcanic ash soils: Genesis, properties and utilization. Elsevier, Amsterdam.Dev. Soil Sci. 21.

Subrahmaniyan K, Kalaiselvan P, Balasubramanian TN, Zhou W (2008). Soil Properties and Yield of Groundnut associated with Herbicides, Plant Geometry, and Plastic Mulch. Comm. Soil Sci. Plant Anal., 39 (7/8): 1206-1234.

Subrahmaniyan K, Kalaiselvan P, Balasubramanian T, Weijun Z (2006). Crop productivity and soil properties as affected by polyethylene film mulch and land configurations in groundnut (*Arachis hypogaea* L.) Arch. Agron. Soil Sci., 52(1): 79-103.

Takashi F, Hajime A (2000). Soil Properties and Tomato Growth and Yield in No-till and Hairy Vetch Mulch Field with Sandy and Volcanic Ash Soils. Bull. Fac. Agric., Niigata Univ., 52(2):157-168.

van der Meulen ES, Nol L, Cammeraat LH (2006). Effects of Irrigation and Plastic Mulch on Soil Properties on Semiarid Abandoned Fields. Soil Sci. Soc. Am. J., 70(3): 930-939.

Wall A, Heiskanen J (2003). Effect of air-filled porosity and organic matter concentration of soil on growth of *Picea abies* seedlings after transplanting. Scand. J. For. Res., 18(4): 344-350

Warrick AW, Myers DE, Nielsen DR (1986). Geostatistical Methods Applied to Soil Science. SSSA, Agronomy Monograph No. 9.