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SOIL POTASSIUM NUTRIENT, TEMPERATURE AND RAINFALL REQUIRED TO GENERATE 'HONEY TASTE' OF CILEMBU SWEET POTATO

Hara Kalsium Tanah, Suhu, dan Curah Hujan yang Diperlukan untuk Menghasilkan Rasa Manis Madu pada Ubi Jalar Cilembu

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ABSTRACT

Indonesia produces normal and "honey taste sweet potatoes" (HTSP), but soil properties and climate factors that govern the unique honey taste and its sugar content have not yet comprehensively evaluated. The objective of the study was to assess and evaluate the soil nutrients and climate factors generating honey taste of Cilembu Rancing cultivar. Soils and plant tissues were sampled at different elevations for various macro- and micro-nutrient analyses and that tubers for sugar analysis. Results showed that the most suitable climate to produce the highest vine and tuber weight, and total tuber sugar of the HTSP was monthly temperature of 21–22^{o}C occurring at 870–917 m soil elevation with monthly rainfall of 96-199 mm. The K nutrient was responsible in part to the high production and total sugar as revealed by significantly positive correlation between soil available K against K content of leaves and tubers, fresh weight of vines and tubers, and total sugar of tubers. The honey taste was driven by type of dominant sugar: fructose > sucrose > glucose. The balance of N, P, K, Ca and Mg to support generation of HTSP for Rancing cultivar was 2,067, 25, 304, 1,824 and 260 mg kg^{-1} soil, respectively. Further, the content of Fe, Mn, Cu and Zn micronutrient was 29, 177, 4 and 2 mg kg^{-1}, respectively. Findings of climate factors and soil nutrients required by HTSP in this study could be used as a guidance to select the new areas for massive development of honey-taste sweet potato.

Keywords: Nutrient balance, potassium, rainfall, sweet potato honey taste, temperature

ABSTRAK

Indonesia memproduksi ubi jalar dengan rasa normal dan rasa manis madu, tetapi sifat tanah dan faktor iklim yang mengendalikan rasa unik manis madu dan kadar gula belum dievaluasi secara menyeluruh. Penelitian bertujuan mengkaji dan mengevaluasi kandungan hara tanah dan faktor iklim yang mengontrol terbentuknya rasa manis madu pada ubi jalar Cilembu varietas Rancing. Tanah dan jaringan tanaman disampel pada berbagai elevasi untuk analisis unsur makro dan mikro. Umbi dianalisis untuk kadar hara dan jenis gula. Hasil penelitian menunjukkan bahwa iklim yang paling sesuai untuk menghasilkan berat batang, daun, umbi, dan kadar gula total tertinggi adalah suhu bulanan 21–22^{o}C pada ketinggian 870–917 m di atas permukaan laut dengan curah hujan bulanan 96–199 mm. Unsur K juga berperan utama dalam produksi umbi tinggi, kadar gula, dan rasa manis madu yang ditunjukkan oleh korelasi positif nyata antara hara K dalam tanah terhadap kandungan K daun dan umbi, berat batang-daun dan umbi segar, serta kadar gula total umbi. Rasa manis madu ditentukan oleh jenis gula dengan urutan dominan fruktosa > sukrosa > glukosa. Keseimbangan hara makro dalam tanah yang diperlukan varietas Rancing untuk memproduksi ubi manis madu adalah N, P, K, Ca, dan Mg masing-masing 2.067, 25, 304, 1.824 dan 260 mg kg^{-1} tanah. Kandungan unsur hara tanah mikro Fe, Mn, Cu, dan Zn adalah berturut-turut 29, 177, 4, dan 2 mg kg^{-1}. Temuan faktor iklim dan hara tanah yang dibutuhkan ubi Cilembu dalam penelitian ini dapat dijadikan rujukan untuk mencari lahan baru yang sesuai untuk pengembangan ubi jalar manis madu secara masif.

Kata kunci: *Curah hujan, kalium, keseimbangan hara, rasa manis madu, suhu, ubi jalar*

INTRODUCTION

World production of sweet potatoes (*Ipomoea batatas* L.) is about 175.3 million tons, with 71.4 million tons produced by China followed by Nigeria, Tanzania, Indonesia and Uganda with 3.8, 3.5, 2.3 and 2.0 million tons, respectively (Food and Agricultural Organization 2015). Other producers are Angola, Vietnam, India, United States and Ethiopia producing less than 1.9 million tons each. Sweet potato is the seventh most important food crop in the world (Flores et al. 2016) and even it becomes a staple food in some areas of Asian countries, e.g. PNG (Fujinuma et al. 2018). In addition, sweet potato is one of the main sources of starch, sugar, alcohol, flour and other industrial products (Lee et al. 2006; Adenuga 2010).

Indonesia produced normal taste and "honey taste" sweet potatoes. The honey taste is visually indicated by a stuff looking like sticky jelly which appears on tubers after roasting. As far as we concern, the comprehensive assessment of soil nutrients, temperature and rainfall required to generate a honey-taste sweet potato of Cilembu Rancing cultivar has not yet appeared in the literature although the Cilembu sweet potato is popularly known in Indonesia. It has been exported to Japan, Hongkong and Singapore. Currently, there are three cultivars (Nirkum, Eno and Rancing) with a honey taste, locally and collectively called “Cilembu” sweet potato. Cilembu name is given as a trade mark to indicate a honey-taste sweet potato, deriving from the Cilembu areas in Sumedang Regency, West Java. Cultivation of honey-taste sweet potato is the main source of farmers’ income in the Cilembu areas.

Due to a famous honey taste of Cilembu sweet potato, for the past five years it continuously received high national and international demand. Unfortunately, this demand is much greater than the supply (local production). Therefore, an attempt should be made to satisfy this demand by looking at new development areas for massive production based on similarity in agroecosystem attributes in the producer center (Cilembu area) of honey-taste sweet potatoes. Agroecosystem attributes are mainly soil properties, topographic conditions and climate factors, but they have not yet systematically studied for honey-taste sweet potato.

Food crop production and quality are driven by genetics, environmental and management factors. A honey taste of a given sweet potato cultivar planted in Cilembu areas (870–916 m elevation above sea level) disappears or drastically decreases if the given cultivar is planted in other areas. This implies that environmental factors (mainly soil properties and climate) play a crucial role in generating the unique honey taste of this sweet potato. The content of soil macro- and micronutrients in Cilembu areas required by honey-taste sweet potato has not yet available.

All crops need essential elements consisting of macronutrients (e.g., N, P, K, Ca, Mg, S) and micronutrients (e.g., Fe, Mn, Mo, Zn, Cu, B) to perform their life cycle. Potassium nutrient is needed by sweet potato for cell division, tuber initiation, enzyme activity and photosynthesis (formation of carbohydrate, and translocation of sugars and mineral nutrients) (George et al. 2002). Petioles have the highest K concentration among sweet potato parts during vegetative growth, and tubers have the highest K accumulation at maturity (George et al. 2002). Soil K nutrient influences tuber yield by increasing the proportion of dry matter conversion to the tubers and increasing tuber number per plant (Bourke 1985).

Recent study on characteristics and sweetness quality of Cilembu sweet potato in various locations indicated that the soil chemical and physical properties, elevation and climate affect the difference in sweetness quality of Cilembu sweet potato (Solihin et al. 2017). This study indicated that Rancing variety of honey taste sweet potato in typical location (Cilembu) contains high total sugar than that in other surrounding locations, but the soil nutrients contributing to honey-taste sweetness were not studied. Hence, the objective of the study was to assess and evaluate the soil nutrients and climate factors generating honey taste of Cilembu sweet potato.

MATERIALS AND METHODS

Location of Study Areas

The location of the study sites was selected at the farms of cooperating farmers at different soil elevations. The study was carried out in the main areas producing honey-taste sweet potato, in Sumedang Regency, West Java, Indonesia. The selected soil sampling used toposequence approach, where Cilembu area located at 870 m above sea level (the center of specific honey taste sweet potato production) was chosen as a reference key area for all soil and climate requirements for a specific honey taste of sweet potatoes.

The study was carried out at six locations (CS1, CS2, CS5, CS6, CS7, CS10) located in Situ Raja, Pamatutan, Cipali, Citali and Salam districts. Soil elevation varied from 347 m to 1030 m above sea levels, designed to allow evaluation of various soil properties associated with temperature on honey-taste of sweet potato. All sites were farmer farms and planted with honey taste sweet potato of the same cultivar, i.e. Rancing cultivar. Rancing cultivar was dominantly cultivated due to its higher yield, shorter maturity (4–5 months) and more resistant to pest and disease (*personal communication with farmer group leader, Mr. Tariana*). Honey sweet potato was cultivated by farmers in a raised bed system (mound construction) of 40 cm high, 60 cm apart and 4–8 m long depending on the slope of the land (increasing length with decreasing slope degree). A single cutting of 40 cm long was planted by farmers on the mound and spacing within the mound was 30 cm, while the growing season lasted for 5 months.

For a given elevation, soils and vines (leaf, petiole and stem) were sampled at 2 months after planting and at harvesting period. The growers have applied a similar crop calendar in all areas, hence the planting time was similar. At a given elevation, soils were sampled using an auger at 0–20 and 20–40 cm depths from 4 raised bed rows with 2 random points each, resulting 8 cores mixed thoroughly and a subsample of about 1 kg for each depth was taken for analysis.

Plant Sampling and Analysis

At 2 months after planting and at a harvesting period, vine samples were cut at ground level, freshly weighed and oven dried for water content determination. Tubers were sampled only during the harvesting period. At the harvesting period, biomass (vines and tubers) was expressed as fresh-weight yields. The fifth to seventh matured leaves, starting from the first unfolded leaf, were taken from four raised bed rows with 10 randomly-selected vines within each raised bed row resulting 40 samples and then composite for analysis. Tubers were manually and carefully dug from the raised bed row using a mattock, cleaned free soils, weighed freshly and sampled for analyses of various nutrient compositions, proximate (water, ash, protein, fat, carbohydrate and energy) and sugar contents.

For plant analysis, vines were separated into leaf, petiole and stem and then oven dried at 70 ºC for 72 hours until constant weight. Leaves, petioles and stems were finely and separately ground for various elemental analyses. The finely ground plant tissues (< 0.5 mm) were digested with concentrated HNO_3 and $HClO_3$ and macro- and micronutrients were determined using atomic absorption spectrophotometer (AAS), except for P and S were measured using spectrophotometer at wave length of 889 and 494 nm, respectively.

The tubers were sliced using a stainless knife prior to drying in the oven and finely ground prior to analysis. Proximate analysis including water, ash, protein, fat, carbohydrate contents and energy were measured according to the method of Association of Official Analytical Chemist (2000). Types of sugars in tubers were determined using high performance liquid chromatography (HPLC). For carbon sequestration, it was referred to summation of C contents in vines and tubers. It was calculated using C concentration in vines and tubers multiplied by dry biomass.

Soil Analysis

The soil particle sizes were determined by the pipette method (Soil Survey Staff 1992). The pH was measured in water with a 1:5 soil solution ratio using an Orion pH meter. The Walkley and Black wet oxidation method was used to determine organic C content (Soil Survey Staff 1992). Total N was determined by the Kjeldhal method (Bremner and Mulvaney 1982). Soil cation exchange capacity (CEC) was determined using a leaching column. The soil was leached with 1M NH_4OAc at pH 7.0 for 1 hour, then the cations were measured in the supernatant (Soil Survey Staff 1992) using an atomic absorption spectrometer (AAS). The CEC was determined in 1M NH_4OAc (buffered at pH 7.0) after extraction of NH_4+ as a measure of CEC by 10% NaCl.

Available P was determined using the Bray 1 method and that exchangeable Al was extracted by 1M KCl as described by Reeuwijk (1993). Potential P_2O_5 and K_2O were extracted using 25% HCl and then measured using spectrophotometer at 889 nm wave length for P and using AAS for K. The available macro- and micronutrients were extracted with sodium acetate and DTPA mixture using a modified Morgan Wolf method (Jones and Wolf 1984).

Sensory Evaluation

Panelists consisting of five experts evaluated a sweetness grade of roasted honey-taste sweet potato using a sensory test technique. Fresh harvested sweet potato was prepared by washing the tubers and then storing them for 2 weeks to maximize sugar content. The tubers were baked at 150–170 °C for 6 hours in an oven. These baked tubers were served to each member of the panelists and they independently assessed and evaluated the attributes by providing hedonic scoring from 1 to 5 (1 very dislike to 5 very like) for visual appearance, aroma, taste, acceptance and sweetness grade.

RESULTS

Soil Texture, pH and Nutrient Availability in the Topsoils

Soil properties were analyzed at 2 months after planting (Tables 1, 2 and 3) and at a harvesting period (Tables 4 and 5). It was expected that either soil analysis would provide the best relationship between the nutrient availability in soils and nutrient uptake in plant tissues: leaves, petioles, stems and tubers. From the positive relationship, types of nutrients responsible for the honey taste and favorable soil conditions for the growth of honey-taste sweet potato could be determined.

Soil properties within the 0–40 cm depth at different elevations at 2 months after planting of sweet potato showed that the soil fine earth (≤ 2 mm) was dominated by clay and silt fractions (Table 1). The clay and silt fractions varied from 25 to 54% and 28 to 63%, respectively, with the texture class of silt loam, silty clay and clay. Soil pH in water at different elevations varied from 5.6 to 6.6 with no trend with elevation. In all cases, soil pH values in water were higher than that in KCl.

Organic C and N in 0–20 and 20–40 cm soil depths varied from 1.3 to 3.0% and 0.1 to 0.3%, respectively (Table 1). Organic C was mostly more than 2% with the lowest values occurring in CS6 and CS11 soils of 1.3–1.9%, and the highest values in CS1 and CS10 soils

Table 1. Soil texture, pH, organic matter and potential P and K at two months after honey sweet potato planting at different elevations in Cilembu areas, Sumedang, West Java.

Soil depth (cm)	Particle size (%)			pH_{H2O}	pH_{KCl}	C (%)	N (%)	C/N	Potential		Available
	Sand	Silt	Clay						P_2O_5 (mg 100 g^{-1})	K_2O (mg 100 g^{-1})	P_2O_5 (mg 100 g^{-1})
CS5 Typic Eutrudept in Sukatali village, Situ Raja district with elevation of 347 m asl											
0–20	11	35	54	5.9	4.5	2.22	0.23	10	262	9	38.6
20–40	5	52	43	5.6	5.2	2.47	0.22	11	248	7	59.8
CS6 Typic Eutrudept in Mulyasari village, North Sumedang district with elevation of 517 m asl											
0–20	16	43	41	5.7	4.8	1.87	0.17	11	164	70	67.2
20–40	14	57	29	6.0	4.6	1.32	0.18	7	112	31	12.7
CS1 Typic Eutrudept in Cilembu village, Pamulihan district with elevation of 870 m asl											
0–20	6	53	41	6.4	6.0	2.28	0.22	10	203	60	77.3
20–40	20	28	52	6.6	5.9	2.54	0.20	13	227	61	88.6
CS11 Typic Eutrudept in Nagara Wangi village, Rancakalong district with elevation of 884 m asl											
0–20	12	63	25	5.6	4.9	1.78	0.18	10	218	23	60.7
20–40	17	45	38	5.7	4.6	1.58	0.14	11	219	19	24.1
CS10 Typic Eutrudept in Sindangsari village, Sukasari district with elevation of 916 m asl											
0–20	16	38	46	6.4	5.3	2.73	0.22	12	218	55	48.6
20–40	13	39	48	6.5	5.2	2.48	0.28	9	219	29	37.9
CS2 Typic Eutrudept in Ciceuri village, Pamulihan district with elevation of 1,030 m asl											
0–20	6	44	50	6.6	5.8	2.30	0.18	13	170	25	75.9
20–40	4	45	51	6.5	5.8	2.36	0.15	16	166	24	67.9

asl is above sea level; CS1, CS2, CS5, CS6, CS10 and CS11 are soil notation at different elevations.

of 2.4–2.6%. The content of organic C and N was not dependent on soil depth and elevation.

Potential and available P_2O_5 varied from 112 to 262 mg 100 g^{-1} (equals to 1,120–2,620 mg kg^{-1}) and 13 to 89 mg kg^{-1}, respectively (Table 1). This indicates that only 1.5–4.7% of the potential P_2O_5 in soil is available (extracted by Bray 1) for crop growth. Potential P_2O_5 content was very high (> 500 mg kg^{-1}) in all soils and was not dependent on soil depth and elevation. With few exceptions, the available P_2O_5 content was higher in the topsoils than that in the subsoils and the magnitude was rated very high in the topsoil while in the subsoil were low in some soils. The trend of potential K_2O content agrees well to the corresponded soil exchangeable K, which is considered available for sweet potato (i.e. the high the potential K_2O the high the exchangeable K).

At low elevations (< 517 m asl), sum of soil exchangeable cations and base saturation were 6.7–8.4 cmolc kg^{-1} and 46–76%, respectively, which were considerably lower than those at high elevation (up to 1,030 m asl) i.e., 9.1–13.6 cmolc kg^{-1} for sum of cations and 62–100% for base saturation (Table 2). In any elevation and soil layer, the magnitude of exchangeable cations was in the order of Ca > Mg > K > Na. Further, the content of available Mn varied from 41 to 169 mg kg^{-1} with the lowest in CS5 and the highest in CS1 soils, while the Fe varied from 46 to 162 mg kg^{-1}. The available Mn and Fe micronutrients showed no clear trend with different soil elevations and soil depths.

Availability of macro- and micronutrients was also extracted by a modified Wolf Morgan method (Jones and Wolf 1984) (Table 3). The content of soil available N was dominant in the form of NO_3 than NH_4. These N contents were below the low rating status of N (< 24 mg kg^{-1}) as defined by this method. A similar situation occurred for PO_4 content (< 6 mg kg^{-1}), which fell far below the low rating P status (< 25 mg kg^{-1}). This low available P disagrees with the available P_2O_5 extracted using Bray 1, which was very high (> 16 mg kg^{-1}) according to this method status criterion. It seems that the Wolf Morgan method was less effective in extracting available P from the soils, probably due to the lesser ability of acetate to displace P from soil adsorption sites compared to the fluorite ion in the Bray 1 method.

The content of available K extracted by a modified Wolf Morgan method (Table 3) and exchangeable K extracted by 1 M NH_4OAc (Table 2) showed good agreement results and the status was rated from low to very high according to the corresponding criterion of the two methods. The highest K content (237 mg kg^{-1}) occurred in the CS1 soil (producer center, 870 m elevation), while the lowest (38 mg kg^{-1}) was in the

Table 2. Soil exchangeable cations, cation exchange capacity, and Fe and Mn at two months after honey sweet potato planting at different elevations.

Soil depth (cm)	Exchangeable cations ($cmol_c$ kg^{-1})					CEC‡	Al	BS† (%)	DTPA (mg kg^{-1})	
	Ca	Mg	K	Na	Sum cations				Fe	Mn
CS5 Typic Eutrudept in Sukatali village, Situ Raja district with elevation of 347 m asl										
0–20	5.36	1.16	0.09	0.04	6.65	13.88	0.18	48	162	41
20–40	6.98	1.22	0.12	0.07	8.39	11.07	0.16	76	132	24
CS6 Typic Eutrudept in Mulyasari village, North Sumedang district with elevation of 517 m asl										
0–20	4.00	1.58	1.07	0.08	6.73	14.56	0.58	46	46	79
20–40	5.76	2.10	0.41	0.10	8.37	15.66	0.23	53	50	94
CS1 Typic Eutrudept in Cilembu village, Pamulihan district with elevation of 870 m asl										
0–20	9.71	1.96	1.28	0.26	13.21	15.22	0.00	87	108	160
20–40	9.69	1.86	1.31	0.17	13.03	14.30	0.00	91	104	169
CS11 Typic Eutrudept in Nagara Wangi village, Rancakalong district with elevation of 884 m asl										
0–20	7.13	1.89	0.33	0.08	9.43	15.25	0.28	62	151	98
20–40	8.23	2.11	0.25	0.15	10.74	12.75	0.09	84	135	103
CS10 Typic Eutrudept in Sindangsari village, Sukasari district with elevation of 916 m asl										
0–20	9.88	2.58	0.97	0.16	13.59	15.10	0.00	90	128	134
20–40	10.08	2.61	0.54	0.21	13.44	11.99	0.00	>100	16	111
CS2 Typic Eutrudept in Ciceuri village, Pamulihan district with elevation of 1,030 m asl										
0–20	6.78	1.73	0.56	0.06	9.13	13.51	0.00	68	46	52
20–40	7.06	1.80	0.62	0.08	9.56	13.29	0.00	72	51	57

‡ CEC = cation exchange capacity; †BS = base saturation; asl = above sea level; DTPA = diethylenetriamine pentaacetic acids

Table 3. Soil macro- and micronutrient availabilities as extracted by Morgan Wolf at two months after honey sweet potato planting at different elevations.

Depth (cm)	Nutrient Availability (mg kg^{-1})												
	NH_4	NO_3	PO_4	K	Ca	Mg	Fe	Mn	Cu	Zn	Al	B	S
CS5 Typic Eutrudept in Sukatali village, Situ Raja district with elevation of 347 m asl													
0–20	3.2	12.6	3.0	38	1,682	175	16.6	105.5	28.6	0.7	1.8	0.5	14.9
20–40	8.3	13.4	3.4	40	2,022	170	11.5	80.9	10.3	0.5	1.2	0.6	9.6
CS6 Typic Eutrudept in Mulyasari village, North Sumedang district with elevation of 517 m asl													
0–20	27.3	175.5	5.0	276	1,481	321	5.4	120.8	91.0	1.2	0.9	0.3	29.2
20–40	19.7	33.3	1.0	46	517	78	6.2	80.4	29.5	1.0	0.6	0.1	21.3
CS1 Typic Eutrudept in Cilembu village, Pamulihan district with elevation of 870 m asl													
0–20	5.4	55.6	4.7	237	3,310	359	9.8	33.2	11.1	0.8	1.5	0.5	3.2
20–40	5.6	42.6	6.3	238	3,672	337	7.0	20.7	5.5	0.7	3.1	0.2	2.1
CS11 Typic Eutrudept in Nagara Wangi, Rancakalong district with elevation of 884 m asl													
0–20	8.6	3.9	4.1	76	2,350	363	16.8	105.7	129.9	1.2	2.7	0.6	2.1
20–40	10.4	3.5	2.5	51	2,029	271	23.3	106.3	151.8	1.4	3.0	0.7	6.3
CS10 Typic Eutrudept in Sindangsari villagei, Sukasari district with elevation of 916 m asl													
0–20	5.7	15.5	3.9	188	3,184	519	16.1	36.9	38.0	1.3	2.5	0.8	3.1
20–40	8.7	14.4	3.1	110	2,541	433	10.9	20.3	6.5	0.8	1.3	0.4	2.1
CS2 Typic Eutrudept in Ciceuri, Pamulihan district with elevation of 1,030 m asl													
0–20	4.1	6.6	5.3	133	2,057	296	6.3	42.9	25.5	1.2	1.0	0.5	2.1
20–40	5.0	11.3	5.1	141	2,115	292	6.0	50.1	33.7	1.1	1.3	0.5	3.2

CS5 soil (347 m elevation). The contents of Ca and Mg mainly varied between 1,481 and 3,672 mg kg^{-1} and 175 and 519 mg kg-1, respectively, with the highest values in CS1, while the lowest Ca and Mg occurred in CS6 and CS5 soils, respectively. The status of Ca and Mg in all soils was sufficient. Micronutrients were very low for Zn and B, while Mn, Cu and Fe were high in all soil layers.

Soil properties at the harvesting period are given in Tables 4 and 5. Soil pH varied from 4.9 to 5.5 but was mostly about 5.2. Soil pH values decreased from 2 months after planting to the harvesting period (Table 1 vs Table 4) in which the pH decreased 1.2 units at high elevation and less than 0.5 unit at low elevation. Exchangeable Ca, Mg and K decreased from 2 months after planting to harvesting period for CS1, CS11 and CS10 soils (high elevation) while increasing for CS5 and CS6 soils (low elevation) (Table 2 vs Table 5). Content of Fe slightly increased in CS5 and CS2 soils but decreased in CS6 and CS1 soils at harvesting period. For Mn micronutrient, there was a slight increase in CS5 and CS1 soils, while other soils were relatively unchanged at harvesting period. At the harvesting period, concentration of Zn and Cu varied between 1–4 and 2–5 mg kg^{-1}, respectively (Table 4).

Biomass of Honey Taste-Sweet Potato

Growth performance and fresh weight of sweet potato biomass are shown in Figure 1 and Table 6, respectively. Growth performance of honey-taste sweet potato of a Rancing cultivar, which was planted in raised beds on terracing systems, and that the exposure of tubers on a broken up raised bed at harvesting time is shown in Figure 1. Crop planted in the raised bed system at 2 weeks after planting showed vigor starting growth (Figure 1a). Vegetative growth at 2 months after planting showed vine coverage for all soil surfaces (Figure 1b), indicating a rapid and high biomass production. The exposure of tubers in a row indicated robust yield with the maximum tuber weight of 1.5 kg (see inserted balance in Figure 1c).

Table 4. Texture, pH, organic matter and micronutrients of selected topsoil composites at harvesting period of honey sweet potato at different elevations.

Sample	Elevation (m)	Texture (%)			pH		Organic matter (%)		C/N	Extract DTPA (mg kg^{-1})			
		Sand	Silt	Clay	H_2O	KCl	C	N		Fe	Mn	Cu	Zn
CS5	347	14	31	55	5.25	4.37	1.62	0.24	7	237	121	2	2
CS6	517	25	38	37	5.49	4.50	1.14	0.20	6	39	58	3	1
CS1	870	16	37	47	5.22	4.58	2.23	0.36	6	29	177	4	2
CS11	884	31	33	36	4.94	4.12	0.73	0.24	3	97	100	2	2
CS9	900	26	31	43	5.24	4.39	1.16	0.33	4	98	147	3	2
CS10	916	10	42	48	4.90	4.09	1.30	0.53	2	190	11	5	4
CS2	1,030	12	35	53	5.45	4.52	1.54	0.22	7	59	53	3	2

CS9 sample locations was similar to CS1 but it belongs to different farmers; Sample notations (e.g. CS5) should consult Table 1.

Table 5. Content of phosphorous, exchangeable cations, cation exchange capacity and Al of selected topsoil composites at harvesting period of honey sweet potato at different elevations.

Sample	Elevation (m)	HCl 25% (mg 100 g^{-1})		Bray1	Exchangeable cations ($cmol_c$ kg^{-1})					CEC	BS	Al^{3+} ($cmol_c$ kg^{-1})	H^+ ($cmol_c$ kg^{-1})
		P_2O_5	K_2O	P_2O_5 ppm	Ca	Mg	K	Na	Sum cation				
CS5	347	171	16	31	6.36	1.51	0.34	0.03	8.24	14.28	58	0.12	0.16
CS6	517	102	35	25	5.89	1.84	0.66	0.05	8.44	17.05	50	0.10	0.18
CS1	870	209	53	91	9.33	1.49	1.07	0.16	12.05	18.12	67	0.08	0.16
CS11	884	164	82	53	5.78	1.26	1.26	0.54	8.84	15.50	57	0.44	0.27
CS9	900	152	77	36	10.07	1.37	1.38	0.05	12.87	25.66	50	0.25	0.17
CS10	916	76	25	32	9.72	2.17	0.49	0.16	12.54	21.73	58	0.46	0.20
CS2	1,030	143	19	70	7.48	1.35	0.55	0.06	9.44	15.60	61	0.04	0.16

BS = base saturation.

CS9 sample locations was similar to CS1 but it belongs to different farmers; Sample notations (e.g. CS5) should consult Table 1.

Number of tubers per plant at harvesting time was 3–5 pieces but mostly 3.

The fresh weight of vines (consisting of leaves, petioles and stems) increased from 27,262 kg ha^{-1} at 347 m to a maximum of 132,447 kg ha^{-1} at 916 m elevation and then decreased to 104,403 kg ha^{-1} with increasing elevation up to 1,030 m. Likewise, the fresh weight of tubers increased from 30,114 kg ha^{-1} at 347 m to a maximum of 55,686 kg ha^{-1} at 916 m elevation and then decreased to 41,222 kg ha^{-1} at 1,030 m elevation.

Nutrient Tissue Composition

Various nutrient compositions of sweet potato tissues at 2 months after planting and at harvesting period are given in Tables 7 and 8. At 2 months after planting, the magnitude of macronutrient constituents was in the order of N > K > Ca > Mg > P or S for leaves, and of K > N > Ca > Mg > P or S for petioles and stems (Table 7). The N content in the leaves, petioles and stems was 3.5–4.9%, 1.5–3.0% and 1.4–1.9%, respectively. For K nutrient, it was relatively similar in leaves and petioles (varying from 2.5 to 3.8%) which in turn was generally higher than that in the stems. Calcium was higher in petioles (0.8–1.2%) than that in the leaves and stems (mostly 0.5–0.8%). For P and Mg contents, they were evenly distributed in leaves, petioles and stems. Further, for micronutrients the order of magnitude was similar in leaves, petioles and stems, i.e. Fe > Mn > Zn > Cu > B (Table 7).

At the harvesting period, the leaves and petioles were mixed for analysis, and the results showed different order of macronutrients at different soil elevations (Table 8). At 347, 517 and 1,030 m elevations, the order of macronutrients was similar N > K > Ca > Mg > P or S. On the other hand at 884, 900 and 916 m elevations, the order was K > N > Ca > Mg > P or S which was different from the nutrient order for the corresponding soil elevations at 2 months after planting (Table 7). Further, the micronutrients order was Fe > Mn > B > Zn > Cu which was different from micronutrient order at 2 months after planting. Comparison of N concentrations between 2 months after planting (3.5–4.9%) and harvesting period (3.4–5.0%) was practically similar. For K nutrient, the content in the leaves was higher at harvesting period than that at two months after planting. In all sampling periods, the comparison of a given nutrient content at different soil elevations showed the K content was higher at 870–1,030 m elevation than that at the low (< 517 m asl) elevation. Other nutrients showed no trend with the soil elevation.

Carbon content showed no clear differences among leaves, petioles and stems, varying from 33 to 45% at 2 months after planting. At the harvesting time, the C content varied from 34 to 38% in a mixture of leaves and petioles and from 33 to 38% in the tubers (Table 8). This narrow range of C content indicates there is no considerable effect of different sampling times and soil elevations.

Macronutrient content in tubers was in the order of decreasing magnitude K > N > P ~ Ca > Mg at 870, 884, 900 and 916 m elevations, while the order at 517 and 1,030 m elevations was N > K > P ~ Ca > Mg (Table 8). For micronutrients in tubers, the order of magnitude was Fe > Mn > B > Zn ~ Cu. Comparison of nutrient content in plant parts showed that the content of N, P, K, Ca and Mg macronutrients were higher in the leaves than those

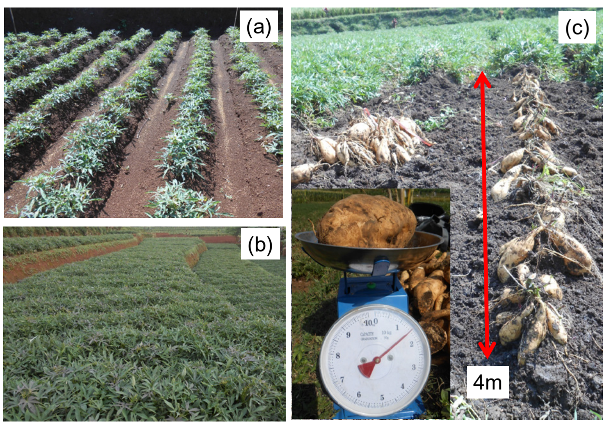

Fig.1. Growth performance of a Rancing cultivar of honey-taste sweet potato in Cilembu areas: (a) Crop planted in the raised bed at two weeks after planting, (b) Crop planted in the raised bed of bench terracing at two months after planting, and (c) Tubers exposure in the broken up raised bed (4 m length) with fresh weight of the biggest tuber of 1.5 kg (inserted picture with a balance) and fresh vines in remainder unharvested raised beds.

Table 6. Fresh weight of vines and tubers at harvesting period of honey sweet potato in Cilembu areas, Sumedang, West Java.

Sample	Elevation (m)	Fresh weight (kg ha^{-1})	
		Vines	Tubers
CS5	347	27,262	30,114
CS6	517	38,735	35,313
CS1	870	na	48,814
CS11	884	72,002	40,597
CS9	900	103,292	55,686
CS10	916	132,447	53,750
CS2	1,030	104,403	41,222

Vines including leaves, petioles and stems.
na = not available.
CS9 sample locations was similar to CS1 but it belongs to different farmers; Sample notations (e.g. CS5) should consult Table 1.

Table 7. Nutrient constituents in leaves, pedials and stems of honey-taste sweet potato at two months after planting at different elevations in Cilembu areas, Sumedang, West Java.

Sample	C	N	P	K	Ca	Mg	Na	S	Fe	Al	Mn	Cu	Zn	B
	%						(mg kg^{-1})	(%)	mg kg^{-1}					
CS5 Typic Eutrudept in Sukatali village, Situ Raja district with elevation of 347 m asl														
Leaf	38.48	4.54	0.25	3.04	0.52	0.32	48	0.19	223	170	125	23	26	18
Pedial	42.01	2.06	0.24	2.86	0.83	0.24	32	0.14	166	181	88	11	19	11
Stem	40.58	1.94	0.24	2.82	0.55	0.32	59	0.11	204	260	54	16	19	14
CS6 Typic Eutrudept in Mulyasari village, North Sumedang district with elevation of 517 m asl														
Leaf	44.72	4.31	0.19	3.03	0.57	0.31	65	0.37	729	172	296	26	25	35
Pedial	33.90	2.08	0.12	2.77	0.81	0.31	65	0.10	193	189	192	15	17	13
Stem	38.32	1.89	0.13	2.95	0.63	0.34	49	0.06	425	258	108	14	18	12
CS1 Typic Eutrudept in Cilembu village, Pamulihan district with elevation of 870 m asl														
Leaf	44.62	4.85	0.22	3.75	0.76	0.39	107	0.27	352	672	144	19	34	18
Pedial	35.16	2.98	0.22	3.15	0.76	0.30	102	0.09	296	514	71	12	20	9
Stem	40.00	1.82	0.20	3.36	0.51	0.28	113	0.09	282	378	43	14	16	10
CS11 Typic Eutrudept in Nagara Wangi village, Rancakalong district with elevation of 884 m asl														
Leaf	40.23	3.54	0.21	3.00	0.53	0.45	64	0.14	392	425	133	17	23	20
Pedial	45.70	1.90	0.23	2.47	0.80	0.24	85	0.18	262	339	65	8	10	13
Stem	37.72	1.46	0.21	2.31	0.62	0.37	43	0.11	349	508	55	12	10	13
CS10 Typic Eutrudept in Sindangsari village, Sukasari district with elevation of 916 m asl														
Leaf	34.27	4.01	0.25	3.11	0.69	0.33	60	0.31	272	203	78	22	25	22
Pedial	34.94	1.51	0.26	3.20	1.04	0.36	66	0.24	241	261	46	11	24	16
Stem	41.46	1.38	0.22	2.69	0.69	0.34	55	0.11	267	339	33	15	21	14
CS2 Typic Eutrudept in Ciceuri village, Pamulihan district with elevation of 1,030 m asl														
Leaf	33.28	4.21	0.25	3.30	0.75	0.40	49	0.24	346	412	172	20	30	13
Pedial	36.26	2.79	0.24	3.66	1.22	0.34	146	0.15	277	433	93	12	17	11
Stem	41.79	1.79	0.28	2.76	0.83	0.44	65	0.10	201	428	78	18	21	12

Table 8. Nutrient constituents in tubers, leaves and pedials of honey taste sweet potato at the harvesting period at different elevations.

Sample	Elevation	C	N	P	K	Ca	Mg	Na	S	Fe	Al	Mn	Cu	Zn	B
	m	%								mg kg^{-1}					
Leaves and pedials															
CS5	347	37.99	3.97	0.18	3.77	1.04	0.75	0.01	0.80	573	741	298	17	21	57
CS6	517	35.42	4.22	0.24	3.58	0.85	0.53	0.00	0.17	378	386	139	18	19	43
CS11	884	34.22	3.38	0.16	3.84	1.45	0.56	0.01	0.29	510	709	270	14	18	38
CS9	900	36.08	4.03	0.15	4.18	1.65	0.64	0.01	0.23	752	1110	196	9	15	44
CS10	916	33.63	4.95	0.41	5.39	1.04	0.45	0.00	0.36	346	537	75	22	26	53
CS2	1,030	35.54	4.54	0.25	4.06	1.59	0.53	0.01	0.38	610	887	454	17	40	44
Tubers															
CS5	347	37.64	1.15	0.18	1.13	0.16	0.07	0.01	0.00	2500	2698	70	9	11	29
CS6	517	37.52	1.45	0.14	1.25	0.14	0.07	0.01	0.00	507	271	19	7	7	14
CS1	870	33.21	1.06	0.14	1.23	0.11	0.08	0.01	0.00	939	733	24	5	6	15
CS11	884	36.84	0.89	0.14	1.30	0.09	0.04	0.01	0.00	366	331	21	5	4	11
CS9	900	33.83	1.74	0.13	1.56	0.13	0.06	0.00	0.00	206	185	11	6	4	12
CS10	916	34.72	0.91	0.15	1.22	0.13	0.07	0.01	0.00	963	747	18	5	5	13
CS2	1,030	35.77	1.84	0.15	1.18	0.11	0.06	0.01	0.00	408	318	25	5	15	12

CS9 for leaf sample location was similar to CS1 sample locations in Table 9 but they belong to different farmers; Sample notations (e.g. CS5) should consult Table 1.

in the tubers. This also holds true for Mn, Cu, Zn and B micronutrients. The effects of soil elevation showed that K nutrient in leaves increased from lower elevations (< 517 m asl) to a maximum of 870–916 m, then decreased at further increasing elevation (Table 8). Likewise, the trend of K nutrient in tubers increased from 1.1% at low elevation (347 m) to a maximum of 1.6% at 900 m, but decreased (1.2%) at further increasing elevation up to 1,030 m.

Proximate, Sugar Contents and Sensory Evaluation of Tubers

Proximate including water, ash, protein, fat, carbohydrate and energy, contents is shown in Table 9. Water content of tubers varied from 65 to 73% (mostly 68%) and that carbohydrate from 26 to 32%.

The highest water content and lowest carbohydrate and energy of tubers occurred at a lower soil elevation in Situraja (347 m asl). At 870–900 m soil elevations, the water content was practically similar (68–69%), while carbohydrate varied between 28% and 31%. The energy content ranged from 108 to 137 calories 100 g^{-1}. Except for the CS11 soil, fat content was low (0.1%) in all locations, while protein varied from 0.7 to 1.7% and was not clearly affected by different soil elevations.

Total sugar content was lowest (< 2.3%) at low elevation (<517 m asl) as indicated by CS5 and CS6 soils and then increased to achieve a maximum (5.7–6.0%) at 870–900 m elevations as revealed by CS1 and CS9 soils and then decreased (4.2%) at 1,030 m elevation (CS2 soil) (Table 9). Type of sugars showed that fructose was the highest followed by sucrose or glucose at 870–900 m elevations (producer center), while at 347, 517 and 1,030 m elevations sugar content was dominated by sucrose followed by glucose and fructose, respectively.

For sensory evaluation including the aroma and acceptance attributes, the panelists stated that all tubers obtained from different soil elevations were not different from each other (Table 10). On the other hand, attributes of appearance, taste and sweetness were significantly different among locations, indicating the effect of soil elevations.

The sweetness scoring varied from 3.1 to 4.6, which was significantly lower (score 3.1) at low soil elevation (347 m asl) compared to high elevations (870–1,030 m). Although sweetness of tubers at 517 m elevation (CS6) was not statistically different from that at high elevations (> 870 m), the absolute value of hedonic scoring was higher for the latter (3.9 vs 4.3–4.6).

DISCUSSION

All soils at different elevations were planted by farmers with the same sweet potato cultivar, a Rancing cultivar, and were based on crop calendar to obtain uniform planting time. Hence any difference in yields and qualities of tubers should be attributed by the difference in temperature and soil properties including textures, structures, drainage, pH, types and concentrations of nutrients, and nutrient balances.

Table 9. Proximate and sugar content of honey-taste sweet potato at harvesting period and different elevations in Cilembu areas, Sumedang, West Java.

Parameter	Sample elevation					
	CS5 347 m	CS 6 517 m	CS 1 870 m	CS 11 884 m	CS 9 900 m	CS 2 1,030 m
Proximate						
Water (%)	72.5	66.2	68.2	68.5	68.8	65.2
Ash (%)	0.6	0.7	0.5	0.9	0.9	0.7
Protein (%)	1.2	1.4	0.7	0.9	1.6	1.7
Fat (%)	0.1	0.1	0.1	1.5	0.1	0.1
Carbohydrate (%)	25.6	31.6	30.5	28.2	28.6	32.3
Energy (calorie 100 g^{-1})	108.2	132.5	125.5	130.0	121.6	137.0
Sugar						
Total sugar (%)	2.32	1.78	5.95	4.19	5.68	4.16
Reduced sugar (%)	0.06	0.06	1.89	1.95	0.98	0.13
Glucose (%)	0.60	0.60	0.76	1.56	0.60	0.60
Fructose (%)	0.50	0.50	1.48	0.69	0.81	0.50
Sucrose (%)	2.20	1.29	1.38	nd	0.50	1.38

Note: Protein (N x 6.25); nd: not determined; Sample notations (e.g. CS5) should consult Table 1.

The Influence of Climate Conditions

Fresh biomass of vines (leaf, petiole and stem) and tubers sharply increased from low soil elevation (347 m) to a maximum at 870–916 m but decreased for further increasing elevation up to 1,030 m (Table 6), suggesting the strong effect of decreasing temperature on the growth of honey-taste sweet potato. The total sugar content was clearly affected by soil elevations, i.e., the order of decreasing total sugar was 870–900 m > 1,030 m > 347–517 m above sea level. This suggested that the temperature is responsible in part to the honey-taste generation in sweet potato.

To thoroughly assess the most favorable real time climate conditions for a specific honey-taste sweet potato production, we took advantage to collect climate data from an automatic weather recording station located at 870 m elevation in Cilembu district (other soil elevations had no automatic weather record station) during the growing period of sweet potato in this study (from March to July 2015) (Table 11).

The climate attributes showed that amount of monthly rainfall occurring from March to May varied between 96 and 199 mm and then it was completely dry during June and July, the time of tuber maturity phase. The humidity was 67–72%, while the sunshine increased from 53% for March and April to 82–92% for May until July. The temperature was relatively constant at 21–22 ^{o}C throughout the crop life cycle. Hence it could be shown that monthly rainfall of 96–199 mm (with the dry month during the end phase of maturity) and the temperature of 21-22 ^{o}C are the most suitable soil moisture and temperature to generate honey taste in sweet potatoes of Rancing cultivar. This finding was supported by Ramirez (1995) who stated that the suitable temperature for vegetative growth of sweet potato during the day time was 20-25 ^{o}C, while the accumulation of photosynthate in tubers occurred during the night time at 15-20 ^{o}C. In Indonesia, it is generally accepted that there is a temperature decrease of 1 ºC for every 100 m increase in soil elevation. Using the reference of temperature of 21-22 ºC at 870 soil elevation, the temperature calculation at low soil elevations (347 and 517 m asl) was 26-27 ºC, which was less suitable for honey taste generation in sweet potato of Rancing cultivar. This is confirmed by the decrease in total sugar content of tubers (Table 9) and a significant decrease in sweetness according to sensory test (Table 10) for the tubers from low elevation areas.

Table 10. Sensory test of roasted honey taste sweet potato planted at different elevations in Cilembu areas, Sumedang, West Java.

Sample	Elevation (m)	Attribute scoring				
		Appearance	Aroma	Taste	Acceptance	Sweetness
CS5	347	2,83^{a}	3,38^{a}	3,45^{a}	3,41^{a}	3,10^{a}
CS6	517	3,79^{b}	3,59^{a}	3,62^{ab}	3,66^{a}	3,91^{b}
CS1	870	3,79^{b}	3,52^{a}	3,86^{ab}	3,69^{a}	4,61^{b}
CS11	884	2,55^{a}	3,31^{a}	3,90^{ab}	3,62^{a}	4,55^{b}
CS10	916	3,41^{b}	3,38^{a}	3,86^{ab}	3,66^{a}	4,25^{b}
CS2	1,030	2,52^{a}	3,66^{a}	4,10^{b}	3,79^{a}	4,24^{b}

Numbers within each column followed by a similar small letter are not significantly different at 0.05 probability level.
Sample notations (e.g. CS5) should consult Table 1.

Soil Properties and Nutrient Contents

Soil texture affects soil chemical and physical properties. In the present study, the class of soil texture planted with honey-taste sweet potato was silt loam, silty clay and clay. These textures within soil depth of 0–20 cm and 20–40 cm were favorable conditions to hold sufficient nutrients and water as revealed by robust honey-taste sweet potato growth (Figure 1). In the study areas, agricultural practice using raised bed system was designed to generate good soil aeration, drainage and friable structure and prevent water stagnations, leading to favorable conditions for tuber formation and development. Further, average soil organic C in 0–40 cm depth varied from 1.6 to 2.6% but mostly the weighted average value in the 0–40 cm depth was 2.4% C at 2 months after planting. This average is similar to the soil organic C (CS1) at typical suitable elevation (870 m asl, a producer centre) for growing honey-taste sweet potatoes. Hence, soil organic C of 2.4% is sufficient for promoting aggregate formation, aeration, and retaining moisture of soils to create favorable conditions for tuber development.

The available micronutrients of Fe, Mn, Zn and Cu were 29–239, 11–147, 1–4 and 2–5 mg kg^{-1}, respectively. The observed Zn content fell within the

Table 11. Climate attributes during the growing period of honey sweet potato at 870 m elevation.

Month	Humidity (5)	Sun shine (%)	Temperature (^{0}C)	Rainfall (mm)
January	71.5	39.6	22.5	178
February	66.3	35.5	19.6	409
March	71.9	53.3	21.1	199
April	70.8	52.0	21.7	123
May	67.4	81.5	22.0	96
June	66.7	88.8	21.8	0
July	68.8	92.1	22.5	0

Source: National Space Aviation Agency in Cilembu district (2015).

range of mobile Zn (NH_4OAc extractable) and that Cu was higher than mobile Cu reported by Doichinova et al. (2014). The mobile portions of Zn and Cu in natural soils ranged from 1.20 to 5.29, and from 0.73 to 1.65 mg kg^{-1} soils, respectively (Doichinova et al. 2014). The observed content of available Fe, Mn, Zn and Cu in this study seems sufficient for honey-taste sweet potato, since there was no symptom of micronutrient toxicity or deficiency during the growing period.

The availability of macro- and micronutrients, and that soil pH showed no trend with soil elevations (Tables 3, 4 and 5), meaning that nutrient variation among soils was associated with different management practices (fertilizer rate, organic matter and lime applications) by farmers. Further, soil pH values were consistently higher in water than that in KCl for all soils indicating that the soils have considerable amounts of negative charge on colloidal surfaces under natural pH conditions (Sumner 1994; Anda et al. 2008) to retain nutrients having a positive charge such as K, Mg, Ca and NH_4. Soil pH varied from 5.0 to 6.6 for all sites during a growing period, and the most suitable pH value was 6.5 during maximum vegetative growing (2 months after planting) as referred to the site of sweet potato center (CS1 soil). Soil pH values decreased from 2 months after planting to the harvesting period (Table 1 vs Table 4) with 1.2 units at the high elevation and less than 0.5 unit at the low elevation. The more decrease in soil pH at the higher elevation was due to the high lime application rate but it was rapidly lost from the soil as a consequence of leaching associated with high rainfall. For example at the 870 m elevation (CS1 soil), the farmer applied lime of 2.0 t ha^{-1} where the pH in the topsoil decreased from 6.4 at 2 months after planting to 5.2 at the harvesting period. Since the exchangeable Al was less than 0.5 cmolc kg^{-1} in all soils, Al toxicity to sweet potato growth would be unlikely. Hence, the effect of lime application was only to increase soil pH associated with changing nutrient availability and improving base cation ratios.

Generally, the content of exchangeable Ca, Mg and Na cations which was lower in the topsoils than that in the subsoils may reflect the mobility of these cations to the subsoils through leaching (Table 2). For exchangeable K, its content was mostly relatively similar in the topsoil (0–20 cm) and subsoil (20–40 cm) for each soil, probably due to split K fertilizer applications (at planting time and 50 days after planting), and that it was banded in the top soils, maintaining K level in the topsoils.

The variation of available P_2O_5 (Bray 1) although potential P_2O_5 (HCl 25%) is high in any given soil indicates some soils have a high P fixation (Table 1). This high fixation was associated with the high Fe, since Al is very low. The status of available P_2O_5 was very high (mostly 39–77 mg kg^{-1}) in all topsoils (Table 1), suggesting that the crop would not experience P deficiency. Potential K_2O varied among soils, where CS1, CS6 and CS10 soils had a high status, while CS11 and CS2 soils had a medium status and CS5 soil had a very low status. This soil potential K_2O status corresponded well to exchangeable K status with low (< 0.3 cmolc kg^{-1}) and very high (> 1.0 cmolc kg-1) content. Variation of K content is attributed to different management practices (different KCl fertilizer application) by farmers in addition to K derived from parent materials.

At the harvesting period, the contents of potential and available P_2O_5 and K_2O were still high in all selected topsoils (Table 5), except for CS5 and CS2 soils that had a low potential K_2O status. The high available P_2O_5 and exchangeable K indicated the high residue of fertilizer in soils, in addition to inherited K natural reserve in soil minerals, suggesting that application of P fertilizers for the next planting season of all soils would be unnecessary. This also holds true for K fertilizer at 870–916 m elevations (CS1, CS11 and CS9 soils), while CS5, CS6 and CS2 soils need K fertilizer application due to lower available K. This observation suggests that periodic soil test is needed to observe the status of nutrient in the soils prior to crop cultivation. The implication is if the residue status of available P_2O_5 and K in soils is high, there is a potential opportunity to reduce cost for crop production and fertilizer negative impact on the environment. Liu et al. (2013) found that the optimum rate of K_2O fertilizer application for sweet potato was 24 g m^{-2} (240 kg ha^{-1}) and potassium increased the sucrose and starch contents of functional leaves in the early growth stage but reduction in the late growth stage. Further they reported that the increased production of storage roots of sweet potato was attributed by optimum amount of potassium to promote supply of photosynthates from leaves during early and middle growth stages and further translocation of photosynthates to storage roots at a late growth stage.

For the available Fe and Mn micronutrients, they were still high in soils at the harvesting period, while Cu and Zn were low (Table 4). Hence, there is a need to apply Cu and Zn to support crop production.

Nutrient Content of Honey Sweet Potato

Concentrations of N, P, K, Ca and Mg macronutrients and that Mn, Cu, Zn and B micronutrients were higher in the leaves than those in the tubers indicated the roles of those nutrients in the formation, translocation and transformation of metabolite to carbohydrate and sugar in a specific honey-taste sweet potato. The maximum total sugar content of tubers was 5.7–6.0% (Table 9) which agrees well to high scoring in the sensory sweetness of sweet potatoes planted at 870–916 m soil elevations (Table 10). The sweetness in normal taste-row tuber of sweet potatoes is due to sucrose, glucose and fructose (Kays and Horvat 1984; Zhang et al. 2002). In the present study, the order of sugar type in honey-taste sweet potato with the maximum sugar content was fructose > sucrose > glucose. This is consistent with the order of sweetness of sugar types, i.e., fructose > sucrose > glucose (Parker et al. 2010). In normal-taste sweet potatoes reported by Lewthwaite et al. (1997), the order of sugar types in row tubers was sucrose > glucose > fructose, which was different from the type of sugar order in honey-taste tubers in the producer center of this study. However, the order of sugar type in normal sweet potatoes reported by Lewthwaite et al. (1997) agrees well to the order of less sweetness (low rating of sweetness sensory test) of honey-taste sweet potato (a Rancing cultivar) if it is planted at lowest and highest soil elevations (347, 517 and 1,030 m). This indicates a significant sweetness loss of honey taste of sweet potato if it is grown on the unsuitable temperature requirement; the suitable temperature is 21–22 ºC (occurring at 870–900 m elevation), while at low elevation the temperature is 26–27 ºC (< 517 m elevation). It is important to emphasize here that the CS11 soil is located at 884 m elevation (fell within the range of honey taste producer center elevation) but the order of sugar type in tubers was glucose followed by fructose, instead of fructose followed glucose. This is due to insufficient available K (0.3 cmolc kg^{-1} exchangeable K) in soil during the growing period (Table 2), while the honey taste will be produced if available soil K is optimal (1.0 cmolc kg^{-1} exchangeable K).

To support the maximum yield and quality of tubers, the required nutrients should be available in a balanced proportion as conditioned by the plant growth requirement, which was referred to nutrient content in crop tissues. Using the criteria of adequate concentration of nutrients in the leaves of sweet potato by O'Sullivan et al. (1997), the macronutrients of N, Mg and K were adequate at 2 months after planting and at harvesting period (Tables 7 and 8). The exception was CS5 and CS11 soils in which N concentration was below the critical concentration deficiency at harvesting time. For P nutrient, its concentration in leaves was mostly at critical value (0.22–0.25%). However, field observation on honey-taste sweet potato growth performance (e.g. Figure 1) at 870–1,030 m soil elevations showed no symptoms of P deficiency, suggesting P was sufficient in tissue leaves. This statement is supported by high availability status of P in soils, which is considered more than enough for the requirement of honey taste sweet potato. Therefore in the present study, the concentrations of Ca (0.5–0.8%) and P (0.20–0.25%) in the leaves were considered sufficient for the honey-taste sweet potato of Rancing cultivar, which are lower than Ca and P requirements of normal sweet potato as reported by O'Sullivan et al. (1997). The adequate concentration ranges of Ca and P in normal sweet potato leaves are 0.9–1.2% and 0.26–0.45%, respectively (O'Sullivan et al. 1997).

The performance of sweet potato growth at 870–916 m soil elevations showed no indication of nutrient deficiency symptoms, while at low elevations (< 517 m) some disorders including small leaf size, shorter stem between nodes and chlorosis were observed. Therefore, the nutrient balance requirement was made for crops at 870–916 soil elevations as a reference of typical requirement of honey taste sweet potato based on the nutrient composition in the leaves associated with the high total sugar content. After 2 months planting, the average ratio of macronutrients in leaves at three locations (CS1, CS11, CS10 soils at 870–916 m elevations) was N : P : K : Ca : Mg = 18 : 1 : 15 : 3 : 2 corresponding to N, P, K, Ca and Mg concentrations of 4.1, 0.2, 3.3, 0.7 and 0.4%, respectively. This indicates that N is needed in a high amount followed by K during the vegetative period. This observation is consistent with Van An et al. (2003) who reported that sweet potato leaves contained high crude protein (26–30%) in dry matter. According to Ishida et al. (2000), the high N content in leaves of sweet potato is attributed to high protein and amino acid contents. Visual field observations showed that most of the leaves at harvesting period remained a normal green (e.g. Figure 1c). This indicates that it is necessary to return sweet potato biomass residue (containing high K) to the soils to avoid exhausted K mining, which leads to K depletion in soils. It is considered that the nutrient balance in leaf tissues for 2 months after planting indicate optimum vegetative growth during a time when the roots very actively uptake large amounts of various nutrients to satisfy the required optimum nutrient balance for metabolism to produce good quality tuber with honey taste sweetness.

In tubers, the balance of macronutrients at 870–916 m soil elevations was N : P : K : Ca : Mg = 8 : 1 : 10: 0.8 : 0.5, corresponding to N, P, K, Ca and Mg concentrations of 1.15, 0.14, 1.33, 0.12 and 0.06%, respectively. It appears that the magnitude of macronutrients in tubers was K > N > P > Ca > Mg, suggesting the dominance of K over other nutrients but both K and N are required in much high amount to generate a honey taste of sweet potatoes. Ravindran et al. (1995) evaluated nutritive values of 16 sweet potato cultivars grown in Sri Lanka and reported that K was the major mineral present in the tubers. In PNG, according to Bourke (1985) the high dry matter and tubers of sweet potato were achieved by application of 225 kg N ha^{-1} in the form of urea and 375 kg K ha^{-1} in the form of KCl. This fertilizer rate indicated that K is required in higher amount than N.

To achieve the required nutrient balance in tubers as mentioned previously, those nutrients should be available in sufficient amount and in balance proportion in soils. Hence the calculation was made for the soil nutrient availability of Ca, Mg, K (obtaining from exchangeable cations), P_2O_5 (Bray 1 and expressed as P) and total N, for the period of two months after planting. The highest total sugar content of tubers at 870–916 m elevations showed that an average macronutrient ratio in soils was N : P : K : Ca : Mg = 82 : 1.0 : 12 : 74: 11, corresponding to N, P, K, Ca and Mg concentrations of 2,067, 25, 304, 1,824 and 260 mg kg^{-1} soil, respectively, for two months after planting. This soil nutrient balance could be used to determine fertilizer rate to produce honey taste sweet potatoes. The high concentration of N in soils probably promoted more availability of K for sweet potato. Du et al. (2015) reported that the addition of NH_4^+ increased the concentration of water extractable K in fertilizer microsites, compared with the application of K^+ alone.

Protein in row tubers that decreased with increasing K content may indicate the role of K in conversion of metabolite to sugar. George et al. (2002) reported that protein tended to decrease with increasing K_2SO_4 application rates in sweet potato.

The effect of elevation and soil exchangeable K was further assessed by plotting total sugar content of sweet potato against elevations and soil exchangeable K (Figure 2). The correlation showed the quadratic relationship between total tuber sugar content and elevation (Figure 2a), meaning that the increased elevation may increase sugar content to achieve maximum at 870–916 m elevations with decreasing effects for further increased elevation up to 1,030 m. The correlation of total sugar of tuber (Figure 2b), K concentration in leaves (Figure 2c) and in tubers (Figure 2d) as a function of soil exchangeable K showed a significant positive linear relationship, confirming K is responsible for generating the honey taste in sweet potato. Based on correlation between total tuber sugars and soil exchangeable K (Figure 2b), the critical concentration (90% of maximum sugar content) of exchangeable K in soils was 1.0 cmolc kg^{-1}. However, it should be noted that environmental factors are also known to contribute to variability in nutrient composition of sweet potato tubers (Purcell et al. 1972;

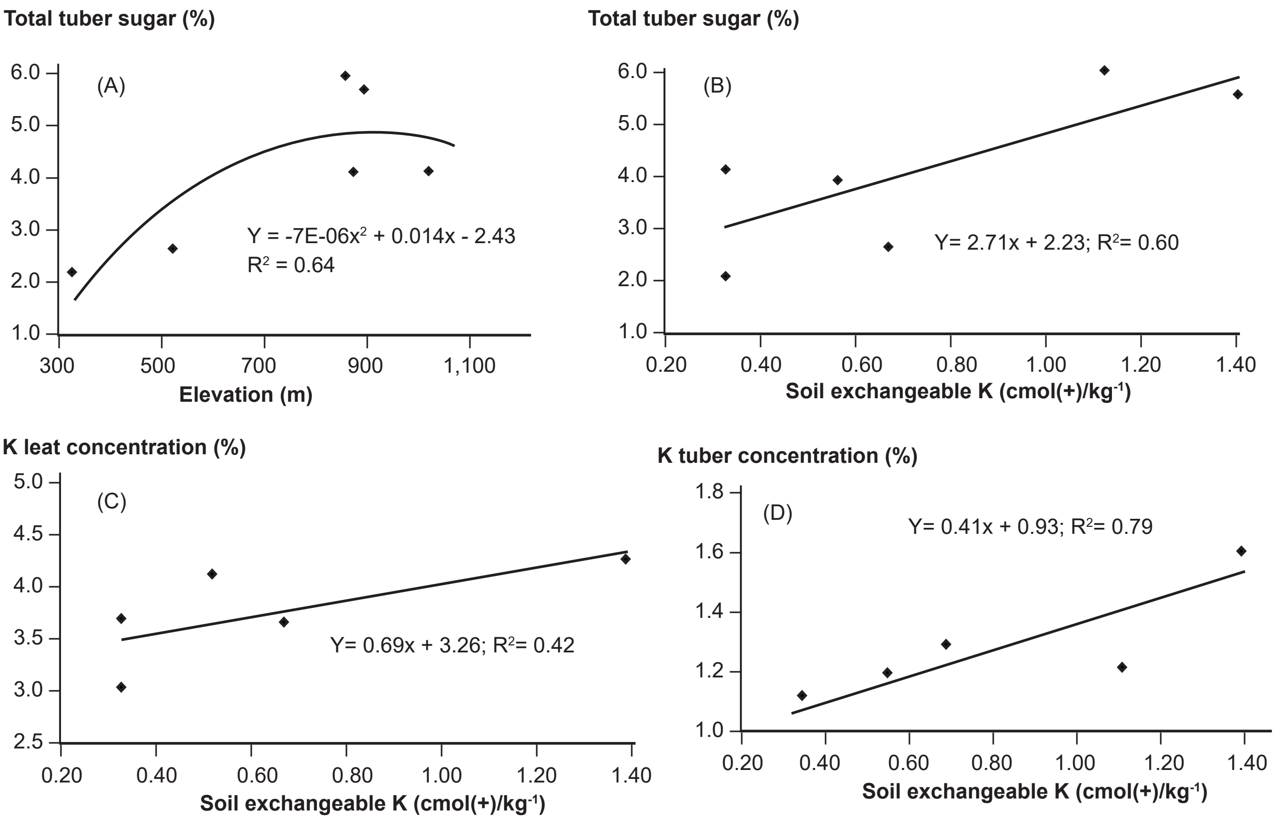

Fig. 2. Correlation between total tuber sugar, leaf K and tuber K against elevation and soil exchangeable K: (A) correlation between total tuber sugar and elevation, (B) correlation between total tuber sugar and soil exchangeable K, (C) correlation between K leaf concentration and soil exchangeable K, and (D) correlation between K tuber concentration and soil exchangeable K.

Walter et al. 1984; Bradbury and Holloway 1998). Hence, rainfall, temperature, soil texture and drainage conditions in addition to soil nutrients should be taken into account in cultivating honey taste sweet potatoes.

The amount of nutrients removed from soils at 870–916 elevations by honey taste sweet potato was calculated based on dry matter crop weight and concentration of nutrients in tissues at harvesting period. The dry matter weight of vines and tubers was 21 and 32%, respectively of fresh biomass (data not shown). The amounts of N, P, K, Ca and Mg nutrients removed from soil in vines were 49, 4.1, 54, 10 and 5 kg t^{-1} dry matter (DM) $season^{-1}$, respectively. Likewise, the amounts of N, P, K, Ca and Mg nutrients removed in tubers were 17.4, 1.3, 15.6, 1.3 and 0.6 kg t^{-1} DM $season^{-1}$, respectively. This indicates huge amounts of N and K removed from the soils. The N removed from soils in leaves and tubers was 873 and 310 kg ha^{-1} $season^{-1}$, respectively, while the corresponding K removed was 907 and 278 kg ha^{-1} $season^{-1}$, respectively. Hence all plant residues should be returned to the soil to avoid serious N and K nutrient depletion.

Calculation of C absorbed by honey taste sweet potato varied from 2.2 to 9.4 t ha^{-1} $season^{-1}$ for vines and 3.6 to 6.0 t ha^{-1} $season^{-1}$ for tubers with the highest value at the producer centre (870–916 m elevation). Conversion of the C absorbed to CO_2 resulted 8.0–34.3 t ha^{-1} $season^{-1}$ for vines and 13.3-22.1 t ha^{-1} $season^{-1}$ for tubers. Summation of absorbed CO_2 suggested that honey taste sweet potatoes had a high ability to sequester CO_2 (21.3–56.2 t ha^{-1} $season^{-1}$) from the atmosphere and preserved it in mass dry matter. Findings from this study showed that the sweet potato had a multifunction impact by contributing to food security from its tubers and sequestrating large amount of C. The latter function has a great positive impact on glasshouse gas mitigation, the current global hot issue on climate change.

Findings of rainfall, temperature, nutrient type and balance in soils required by honey taste sweet potato provide a comprehensive approach in soil management to improve quality of the tubers. These soil properties and climate factors could be used as a guide to evaluate land suitability for new massive development areas for honey taste sweet potatoes to support food security.

CONCLUSION

Soil exchangeable K and temperature are responsible for generation of honey taste in sweet potato Rancing cultivar. The required soil exchangeable K is 1.0 cmolc kg^{-1} and monthly temperature is 21–22 ^{o}C accompanied by monthly rainfall of 96–199 mm. The honey-taste sweet potato in the producer center contains sugar types in the order of fructose > sucrose > glucose, while in the non-producer center, the order of sugar types is sucrose > glucose > fructose, which is the same order for sugar type in normal taste sweet potato.

The typical honey taste of sweet potato, observed at 870-916 m soil elevations, has a macronutrient balance of N : P : K : Ca : Mg = 8 : 1 : 10 : 0.8 : 0.5 in tubers corresponding to soil macronutrient balance of N : P : K : Ca : Mg = 82 : 1.0 : 12 : 74: 11. This balance concentrations correspond to 2,067, 25, 304, 1,824 and 260 mg kg^{-1} soil of N, P, K, Ca and Mg, respectively.

The findings of rainfall, temperature, elevation, soil properties especially K content, macronutrient balance, and micronutrients in this study may be used as a guide for evaluation of new locations for expansion of honey taste sweet potato to satisfy both continuous national and international demands.

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