AN AGRO-ECOLOGICAL ANALYSIS OF *WEN-TINAK*, A SUSTAINABLE SWEET POTATO WETLAND PRODUCTION SYSTEM IN THE BALIEM VALLEY, IRIAN JAYA, INDONESIA

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ABSTRACT

Wen-tinak is the sweet potato wetland production system currently used by Dani people who live in the Baliem Valley. This system was designed specifically for poor soil with a high water table. Recent studies have revealed that the system converts a relatively unfavourable situation into an environment with improved chemical and physical conditions favourable for sweet potato production. The kinds and functions of agronomic activities conducted, and the nutrient cycles involved in wen-tinak are discussed.

INTRODUCTION

The Baliem valley, first seen by outsiders in 1938 (Haberle *et al.*, 1991), is especially noteworthy in three respects. First, the Baliem valley, an area of 960 km^2, is the most prosperous and densely populated valley in the central mountain range of Irian Jaya. The population density of 266 people per km^2 is very high; the population density of Irian Jaya as a whole is only 2.8 people per km^2. Despite its high population density, the valley provides an adequate amount of food supply through subsistence agriculture which is the only food production system practised in this valley.

Second, soils in the valley are developed from limestones and are potentially poor and infertile. Nitrogen and potassium contents of the soil are low while phosphorus is high (Schroo, 1963). Soil reactions range from acid to slightly acid. Soil texture is silty clay loam and the soil structure ranges from blocky to crumb.

Third, the Baliem valley is a tropical high-mountain valley lying at an altitude between 1500 and 2000 m. The average temperature is about 19°C. The annual rainfall is 1800 mm with 195 days of rain. The intensity of solar radiation in this area is low. Incident radiation has been calculated to be 1.38 kJ cm^{-2} per day. In addition, the average daily sunlight duration is only 3.98 hr per day, and the sky is cloudy most of the time.

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Sweet potatoes produced by a sustainable production system are the main crops in the Baliem valley of Irian Jaya. They are planted on raised gardens either on hill sites or on the valley floor. The two general sweet potato production systems carried out by the local farmers are wet soil and dryland cultivation systems. Dryland gardens are usually found on hill sites and on areas far from a river. Most of the area of the valley floor is taken up in dryland gardening where the soil has a low water table. Only lands adjacent to water courses are used in the wetland garden system.

A wetland garden produces a high root yield, between 20 and 25 t ha^{-1} of fresh roots, without applying any chemical fertilizers. The maximum production of the dryland gardens where fertilizers are not used is only 10 t ha^{-1} of fresh roots. Soil fertility in dryland gardens is less than that in wetland gardens.

Although low solar radiation intensity and the low soil potassium content would seem to be unfavourable to the production of high yields of sweet potatoes, yields are nevertheless high and food production is sufficient. Evidently, the existing sweet potato production system, especially in wetland gardens, has been developed to overcome the environmental constraints of the valley.

This recent study of the wetland garden system was designed to analyse the functions of each step of the agronomic practices conducted by the Dani farmers to produce sweet potatoes in their raised fields surrounded by water-filled ditches.

Wetland cultivation system

Wen-tinak is the local name for sweet potato wetland gardens conducted on areas characterized by a soil with a high water table. The wetland gardens are found in the vicinity of swamps around ponds or in the course of rivers in the bottom of the valley. Wetland gardens are dissected by closed canal networks. The main canal is connected to a nearby river or a swamp to fill the canals with water and the height of water in the canals is controlled by a simple gate connecting the main canal to a river. Sweet potatoes are grown on rows of mounds built on the surface of raised beds 5 to 20 m long and 2 to 3 m wide, surrounded by ditches 1 m deep and 1.5 m wide (Figure 1).

A wetland garden of 20 to 30 ha is collectively prepared and owned by farmers living in nearby villages and usually they have three collective gardens located in different parts of their lands. The area of a collective garden depends on the number of farmers and their families involved. After being prepared, the wetland garden is divided into a number of small gardens provided for each farmer and the area of each garden depends on the size of his family. A farmer's garden consists of several plots, mostly rectangular form. However, only some plots are cultivated with sweet potatoes at the same time, the number of plots on which sweet potatoes are grown at the same period of planting time depends on the amount of food required for the daily needs of the family.

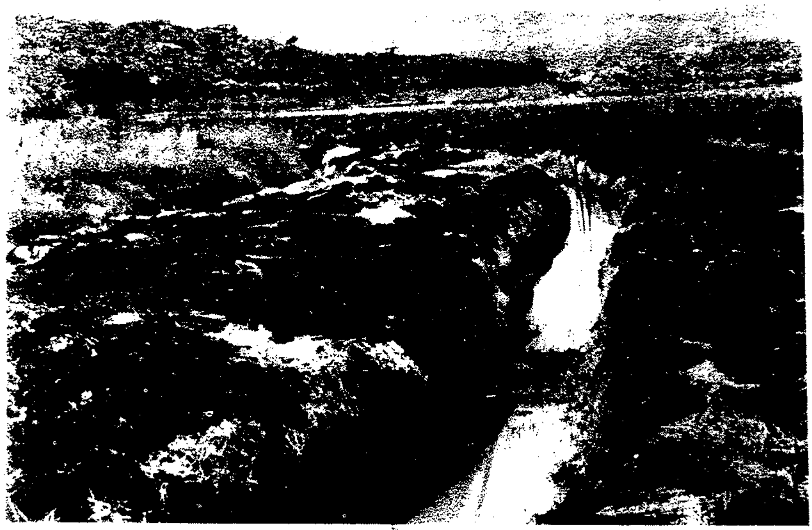

Figure 1. A sweet potato wetland garden on the floor of the Baliem valley. Raised beds are surrounded by water-filled ditches that form a closed canal network.

A new collective garden, is usually derived from a forest or an old garden that has been abandoned for 5 to 7 years. The new garden is prepared according to a sequence of traditional practices which can be categorised as the activities to prepare a garden and the activities to maintain both the garden and the sweet potatoes grown in it. The first activities are to clear the forest or the old garden, to dig ditches and build raised beds with soil taken from the ditches. The ditches form a closed canal network and connect the main canal to a nearby river. Then, the farmers cut grasses that grow in this land, spread them evenly on the surface of the raised beds and burn them after they are dry (Figure 2). About ten days after grass burning, new grass seedlings usually start to grow. For the Danis, this is the right time to cultivate the surface of the raised beds, so they construct mounds on the raised beds and plant sweet potatoes on the top of the mounds. The second activity starts four weeks after planting. Grasses growing along the ditches are cut and buried on the bottom of the ditches. Then they dredge layers of mud from the bottom of ditches, spreading it on the surfaces of both raised beds and mounds (Figure 3).

After the mud layers dry, they are broken up and mixed with the soil of the mounds. (Figure 4).

Figure 2. Grasses are cut and spread evenly on the surface of a raised bed to dry and then the grasses were burnt.

Figure 3. Mud from the bottom of a ditch is dredged out and then spread on the surface of the raised beds. This considered the most important work in a sweet potato wetland garden.

Activities mostly conducted by women, are cutting apical shoots, pruning long stems and cutting young fibrous roots growing either on the bottom part of a sweet potato plant or on a tuberous root. Cutting the apical shoots is carried out three to four weeks after planting. Pruning sweet potato plants having long stems are conducted by the women five months after planting. It seems that this activity is to make sweet potato stems short and to reduce the number of old leaves. The pruning is carried out each time the women visit their gardens. They bring the cuttings home and select some good cuttings that can be used as planting materials. The rest are cooked for their supper.

Figure 4. Flakes of dry mud layers which are rich in organic matter and in nutrients are laid on the surface of the mounds.

Five to six months after planting, tuberous roots usually have been formed. This is the time for the farmer to break open the mounds, to cut all new fibrous roots growing on the bottom part of a sweet potato plant and on tubers, and then to reconstruct the mounds so that the tubers could grow bigger. Seven months after planting, the farmer lets grasses and weeds grow on his raised beds as well as along the ditches in order to get a sufficient amount of grass to be used in the next planting season.

Under the prevailing conditions of the Baliem valley, the farmers start to harvest their crops eight months after planting. Sweet potatoes are harvested daily and harvesting continues for about three to four months. Throughout the growing period, height of water in the canal is controlled and is taken care of by the chief of the local clan

Figure 5. Planting seasons are carried out in parallel. Sweet potatoes and taros grown on the right-hand bed will soon be ready for harvesting. A raised bed on the left-hand side is being prepared for a new planting, for which the mud layer in the ditch is provided.

MATERIALS AND METHODS

The study was conducted in Aikima village in the Baliem Valley from June to September 1986 on farmers' collective wetland garden of about 20 ha. Five family gardens in different stages of sweet potato growing were used as garden samples. The average area of a family garden was about 1.500 m^2 in which about 800 mounds were formed on the surface of raised beds. The family garden consisted of several raised beds surrounded by ditches and a number of mounds on the surface of each raised bed. The size of each raised bed was about 3 m wide, 5 to 20 m long and 1 to 1.5 m high from the bottom of a ditch. The width of a ditch was about 0.6 to 2 m and the water height was between 0.40 and 0.70 m from the bottom of a ditch so the water level in a ditch was between 0.60 and 0.80 m below the surface of a raised bed. The average distance between the tops of two mounds located in one row was 99 cm and the average distance between adjacent rows was 114 cm. A mound had a form like a cone or an irregular pyramid of 35 cm high, 100 cm long and 87 cm wide.

The five garden samples consisted of an uncultivated newly prepared garden and four established gardens in which sweet potato plants had been grown for two, three, seven and ten months, respectively. Two adjacent plots of each garden sample were taken as plot samples and they were considered as a pair of plots.

Each pair of plots was regarded as a system which consisted of seven subsystems, three inputs and two outputs. The seven subsystems were bed soil, mound soil, mud layers in the ditch, mud layers on raised beds, grasses, sweet potato plants and crop-residues. The main inputs were energy of solar radiation, rainfall water and manpower. Harvested materials were regarded as the only output in this cultivation system. The harvested materials consisted of tuberous roots and cuttings of sweet potato plants.

In the period of four months, observations were conducted on sweet potatoes in growing stages of one to 13 months old. Three samples of sweet potato plants, weeds, soil, ditch water and of mud were randomly taken from each plot at three week intervals. The dry weight of leaves, vines, roots as well as tuberous roots were measured based on these samples. The nutrient content of soil, mud, ditch water, sweet potato plants were analyzed to study the pattern of nutrient cycling in the wetland garden system. Solar radiation intensities were calculated by using the Black formula (Chang, 1968) based on local daily sun duration during the course of the study.

Nutrient loads were estimated in units/100 g of soil and then converted to g m^{-2}. The surface area of mound was calculated by first pattening it, calculating its volume and mass dividing by the height. Similarly for the mud that was spread on the surface of a mound, the thickness of the mud was measured and the mass calculated.

For the potato plants, area was the area of land occupied by the plant and for the grass, area was taken to be the surface area of the raised bed from which the grass sample was taken.

RESULTS AND DISCUSSION

Sweet potatoes can be cultivated on different kinds of soils. However, only plants that are grown on sandy loam with high content of soil organic matter and of potassium, and accompanied by a good drainage condition would grow well. A condition with high solar radiation is also needed by sweet potatoes to produce high tuber yields. In the Baliem valley, the main physical constraints for sweet potatoes to produce high tuber yields were soil texture, which was dominated by clay loam, soil with a block structure, and soil with a high water table. Both low radiation intensity and low air temperature were also unfavourable conditions for sweet potato cultivation. In addition, soils in the Baliem Valley were poor in potassium (Schroo, 1963).

In spite of the physical and chemical constraints existing in the Baliem Valley, the first impression of living in the Dani community was that they had sufficient food supply. Sweet potatoes grown on wetland gardens produced good yields (20-25 t ha^{-1}), while the yields of dryland gardens were slightly poor (10 t ha^{-1}). In both gardens, it was clearly seen that the Danis practiced clean weeding to maintain their gardens in a good shape. The wetland system used by the Danis probably modified unfavourable conditions into an environment with improved physical and chemical conditions, favourable for sweet potato production.

Modification of physical conditions

Water in the canal network has many functions which may change both the physical and chemical conditions of its surroundings. Among its functions are to control the height of a soil water table of a raised bed surrounded by the canal and to decrease the amplitudes of soil temperature waves in the raised bed. During the period between June and September, the water surface in the canal between two raised beds fluctuated from 60 to 80 cm measured from the surface of the raised beds. The average of soil moisture content of the raised bed was 78%.

The moisture content of mound soil varied with the increasing height of the position from which a soil sample was taken from a mound. At the bottom part of the mound, the average moisture content was 48%, the middle and top parts were 40 and 25%, respectively. As sweet potato plants require a slightly dry period to form tuberous roots (Hahn, 1977), the conditions found in the mound were beneficial for the sweet potato which was grown on it.

The decrease of soil temperature caused by flooding may range from 5 to 15°C into 10 cm soil depth (Geiger, 1959). The average soil temperature of a raised bed at 5 cm depth was 21°C and temperatures varied by about 3.3°C. An environment with soil temperatures between 21 and 27°C is the optimum required for the growth of sweet potato plants (Hahn, 1977).

The construction of mounds may trap short wave radiation and it may also reduce the emission of long wave radiation from the earth (Oke, 1978). This may cause the temperature around the mounds to be higher and its fluctuation smaller than that of their surroundings (Rosenberg, 1974; Oke 1978).

As the sweet potato plant was grown on the top of a mound, its vines and leaves spread over the slope which had a surface area of about 10.000 cm^2. There were two factors that were responsible for sweet potato plants grown on a mound producing a high yield. First, vines and leaves of the sweet potato plant spread to follow the slope of the mound. The slope formed an angle of about 53°C with the surface of a raised bed. Thus it seems that light interception by sweet potato leaves would be more effective than that which occurred on the horizontal surface of a raised bed. Second, the sweet potato plant occupied a larger surface area. This condition might reduce the number of leaves that caused mutual shadow. This meant that the plant could have many more leaves to intercept solar radiation. Under these conditions, the sweet potato plant had a greater capacity to produce high tuber yields.

Modification of chemical conditions

Soil of the dryland garden was less fertile than that of *wen-tinak* (Table 1). The higher phosphorous and potassium content in the soil of the wetland garden might be associated with the high content of organic matter in *wen-tinak* soil and this implied that the agronomic practices of the Danis improve the fertility of their gardens. This is in concordance with the Dani's belief that sweet potato tubers will grow well and their gardens will produce high yields if they follow the sequence practiced by their ancestors.

The Danis consider that to dredge a rich layer of mud from the bottom of a ditch and spread it on the surfaces of both raised bed and mounds is the most important work in *wen-tinak*. Results of chemical analysis presented in Table 2 showed that the mud taken from the bottom of a ditch was rich in soil nutrients, high in available nutrient content and was also high in CEC.

Since the nutrient content of the mud was higher than that of the raised bed soil, this indicated that a nutrient enrichment process occurred in the mud which was formed under reduced conditions. This implied that a water-filled ditch acted as a nutrient trap. This was similar to the function of seasonally flooded wetlands that are found in the surrounding of a swamp or a lake (Johnston *et al.*, 1984).

Table 1. Soil nutrient contents of dryland and wetland gardens in the Baliem Valley, Irian Jaya which were taken from gardens that had been cultivated for one year.

	Dryland (%)	Wetland (%)
C	2.8400	3.0600
N	0.2184	0.3703
Total-P	0.0047	0.0514
Total-K	0.0090	0.0318

Table 2. Soil nutrient content of a wetland garden in the Baliem Valley, Irian Jaya. Soil samples were taken from a wetland garden that had been cultivated for one year.

		Raised bed	Mound	Mud	Increase (%) bed→mound
pH		5.25	5.53	5.50	
C	(%)	4.33	4.78	6.99	10
N	(%)	0.38	0.42	0.53	11
Total-P	(mg/100 g)	52.00	74.67	86.53	44
Available-P	(ppm)	30.00	62.77	31.20	09
Total-K	(mg/100 g)	32.50	51.67	41.33	59
Available-K	(mg/100 g)	0.20	0.43	0.35	15
Ca	(mg/100 g)	13.90	14.03	15.91	101
Mg	(mg/100 g)	1.35	2.00	1.88	148
CEC	(mg/100 g)	25.60	25.33	33.97	-

The mound, which was rich in soil nutrients, was formed from soils taken from the surface of raised bed. This suggested that its high nutrient content was derived from the mud being applied to its surface. About 165 t ha^{-1} of dry mud containing 875 kg of N, 5 kg of P_2O_5 (available-P) and 23 kg of available-K was spread on their gardens and thus, could be compared to fertilizer application. This process is similar to the effect of sewage sludge applied to agricultural lands (Epstein *et al.*, 1976).

In addition, the high content of soil organic matter in the mounds might influence changes in the structure of the mound soil from blocky to crumb. The latter is the soil structure that is favourable for sweet potato plants to form tuberous roots. Moreover, its high content of total-K and of available-K made the mound soil a good growing medium that allowed sweet potato to produce a high tuber yield. The most important effect of K on sweet potatoes is to enhance the development of tuberous roots (Tsuno, 1971).

Ashes, which resulted from grass burning, contain soil nutrients that are available for plants, short term (Cox & Atkins, 1979). Grass burning conducted by the Danis did not significantly change the soil nitrogen content of raised beds. It slightly increased total-K, but significantly reduced total-P (Table 3). The increase in total-K in raised bed soil which occurred after grass burning was 0.0013% or 26 kg ha^{-1} of K_2O. However, this result was lower than the potassium content of dry grass which was 39.94 kg ha^{-1} of K_2O.

If we compare the results of soil analysis reported by Soepraptohardjo *et al.* (1971) with the results presented in Table 2, it shows that the nutrient content of soils in the Baliem Valley was relatively stable over a period of 15 years. This might indicate that the wetland agriculture system conducted by the Danis not only improves but also maintains the fertility of the soils.

The *wen-tinak* devised by the Danis' ancestors is similar to what was known as *chinampa* agriculture, conducted by the Aztec people in the Mexico Valley several hundred years ago (Cox & Atkins, 1979). Another ancient system is the Tiwanakans' vast drainage system devised by the ancestors of the Aymara Indians living in the Andean highland villages of Bolivia (Knox, 1991). The successful potato harvest following the rediscovery of the Tiwanakan's system has been reported in 1991.

Table 3. Soil nutrient contents of raised bed before and after grass burning. Soil samples were taken from a sweet potato wetland garden that had been cultivated for one year

	Before (%)	After (%)
C	3.2267	2.6467
N	0.3767	0.3750
Total-P	0.0865	0.382
Total-K	0.0179	0.0192

Nutrient cycles in the wen-tinak system

To understand how the *wen-tinak* system could improve soil fertility, it was assumed that the system consisted of seven subsystems and two outputs (Figure 6). The subsystems were raised beds, mounds, mud layers in a ditch, mud layers on the raised beds, grasses, sweet potato plants and crop residues. The two outputs of the system were tuberous roots harvested daily and sweet potato cuttings for use as planting materials and vegetables.

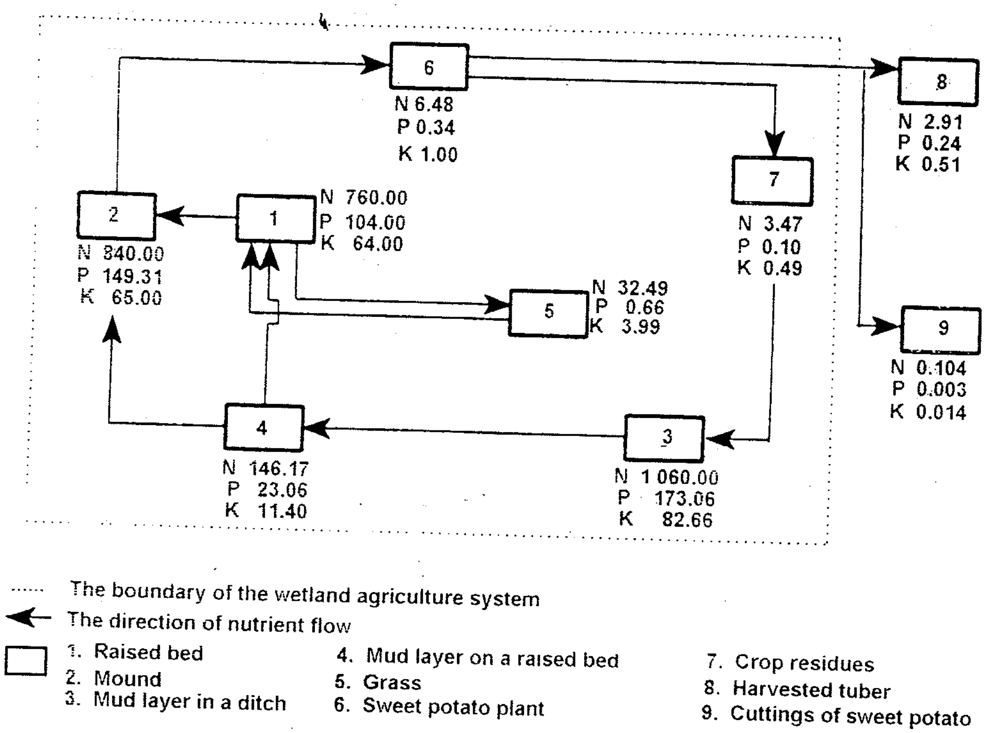

Figure 6. The suggested flow of soil nutrients in g m^{-2} from one subsystem to the others occurring in *wen-tinak*, a sweet potato wetland cultivation system conducted by Dani people living in the Baliem Valley.

The raised bed was the only source of soil nutrients directly provided for sweet potatoes and vegetable crops grown on it. A part of the nutrients absorbed by the plants would either directly or indirectly return to the raised bed. Grass burning and litter burying were considered as the direct way of the nutrients to return to the raised bed. The decomposed crop residues that mixed with the mud on the bottom of the ditch were the indirect means to bring the nutrients back to the raised bed. It was assumed that the soil nutrient contents of the raised bed and of a mound would be as much as those in soil samples (Table 2). The raised bed potentially provided 760 g m^{-2} of N, 104 g m^{-2} of P_2O_5 and 64 g m^{-2} of K_2O for crops that were grown on it.

A mound was constructed from the soil of a raised bed surface after dried grasses had been burnt and the soil had been lightly hoed. The average weight of soil in a mound was 101.1 kg which potentially supplied about 640 g m^{-2} of N, 149.31 g m^{-2} of P_2O_5 and 65 g m^{-2} of K_2O.

The function of water in the ditch remained unknown though it is hypothesized that the water functions in temperature control. Results of water analysis indicated that the nutrient content of the water in the ditch was very low and its contribution to the soil fertility was not significant. However, the water-filled ditch probably acted as a nutrient trap in which the decomposed crop residues were mixed with mud and deposited on the bottom of the ditch. The mud layer on the bottom of the ditch contained 1060 g m^{-2} of N, 173.06 g m^{-2} of P_2O_5 and 82.66 g m^{-2} of K_2O.

In the sweet potato wetland cultivation system, a layer of mud with a thickness of 4 cm was used to cover the surfaces of both raised bed and the mounds. The average weight of the mud layer covering a mound was 31 kg. The nutrient contents provided by this mud layer were 146.17 g m^{-2} of N, 23.86 g m^{-2} of P and 11.40 g m^{-2} of K_2O.

The weight of dry grasses covering the surface of the raised bed was 3.8 kg m^{-2} that contributed 32.49 g m^{-2} of N, 0.66 g m^{-2} of P_2O_5 and 3.99 g m^{-2} of K_2O. Changes in soil nutrient contents of the raised bed after grass burning are presented in Table 3.

The average fresh weights of a sweet potato plant and of its tuberous roots were 2.4 kg m^{-2} and 4.3 kg m^{-2}, respectively and average dry weights were 469 g m^{-2} and 1 336 g m^{-2}, respectively. The nutrient contents of sweet potatoes at eight months after planting were 6.48 g m^{-2} of N, 0.34 g m^{-2} of P_2O_5 and 1.00 g m^{-2} of K_2O. This indicated that nitrogen was the soil nutrient most absorbed by sweet potato plants in the Baliem Valley, while phosphorus was the least.

Sweet potato plants started to be harvested eight months after planting. Only harvested tuberous roots were taken out from the gardens, while vines and leaves remained in the system. After harvesting the tubers the vines and leaves were buried on the bottom of the ditch. These crop residues decomposed under anaerobic conditions and the released nutrients into the mud. The average fresh weight of the crop residues was 2.4 kg m^{-2} containing 3.57 g m^{-2} of N, 0.10 g m^{-2} of P_2O_5 and 0.49 g m^{-2} of K O.

Two main outputs of the agro-ecosystem of *wen-tinak* were tuberous roots and cuttings of sweet potato plants. The average fresh weight of tuberous roots taken out from the system was 4.3 kg m^{-2} containing 31% of dry matter. The amount of plant nutrients removed from the garden through harvested tubers was 2.91 g m^{-2} of N, 0.24 g m^{-2} of P_2O_5 and 0.51 g m^{-2} of K_2O.

In the period between five and eight months after planting, the number of sweet potato cuttings carried away from the system was 115 g m^{-2} of fresh weight. About 40 g m^{-2} provided new planting materials and 75 g m^{-2} were consumed as vegetables.

Accumulation of soil nutrients which continually took place on the bottom of the ditch from one planting season to the others and the use of mud layer to cover raised bed made soil nutrient content in the raised bed soil high. The differences between soil nutrients in bed soil (subsystem 4) and those absorbed by sweet potato plants (subsystem 6) in this study were 139.69 g m^{-2} of N, 23.52 g m^{-2} of P_2O_5 and 10.40 g m^{-2} of K_2O.

CONCLUSION

Wen-tinak is a system of raised beds, mounds and canals developed by the Dani people to overcome unfavourable conditions for sweet potato production in the Baliem valley. By employing a sequence of agronomic activities devised by their ancestors, the Danis succeeded in converting the unfavourable situation into an environment with improved physical and chemical conditions, favourable for sweet potato production.

The main factor that affected the improvement of crop environments was the canal which acted as a nutrient trap in which nutrient enrichment processes occurred. The other agronomic activities might improve sweet potato environments either physically or chemically. Accumulation of nutrients occurred in both raised beds and mounds after one cycle of growing sweet potatoes in the *wen-tinak*.

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