Cassava-Based Intercropping Systems on Sumatra Island in Indonesia: Productivity, Soil Erosion, and Rooting Zone

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Abstract: In Gunung Batin, the southern end of Sumatra Island, Indonesia, cassava is widely cultivated on gently sloping areas for starch materials. The monoculture system and/or the intercropping system without legume plants commonly adopted in this region may tend to accelerate soil degradation. The objective of this study is to compare the productivity among several cassava cropping patterns to propose the most beneficial one in this region. A field experiment of five cropping patterns {cassava (Manihot esculenta Crantz) single-cropping, three cassava-based intercropping patterns, and a crop rotation} was conducted for three years. The cropping pattern that recorded the highest net income varied with the year. In 1997, the driest year of the past several decades, cassava single-cropping was the highest in income. The proposed intercropping system {cassava/(maize → soybean → cowpea)} was the highest in 1998, a year with moderate rainfall. In 1999, when severe insect damage occurred to legume crops, the farmers' conventional intercropping was the highest. In an average of the three years, the proposed intercropping pattern was same as cassava single-cropping, although cowpea cultivation as the dry season cropping was not possible in this region. The amount of soil erosion was relatively high in cassava monoculture in comparison with the other intercropping and crop-rotation systems. Cassava roots penetrated to only 0.5 m deep and extended 1 to 2 m in a horizontal direction depending on the planting density. These results lead to the conclusion that the proposed cassava cropping system would be the most beneficial in terms of economy and control of soil erosion.

Key words: Cassava, Crop rotation, Intercropping, Manihot esculenta Crantz, Mulching, Rooting depth, Red acid soil, Soil erosion.

Cassava is one of the most important calorie-producing crops in the tropics (Kawano et al., 1978). In Gunung Batin, the southern end of Sumatra Island, Indonesia, cassava is widely cultivated on gently sloping areas for the production of starchy materials. The soil in this region is classified as a red acid soil (Acrisol), which is known to rapidly lose fertility after it is reclaimed for cultivation (Lumbanraja et al., 1998; Iijima et al., 1999; Iijima et al., 2003). The monoculture system and/or intercropping with cereal crops, such as maize and upland rice, which are commonly adopted in this region, may tend to accelerate soil degradation. Because soil erosion is one of the major problems for continuous use of cassava field in several regions in Indonesia, the amount of erosion has been evaluated under different cultivation techniques, such as fertilization rates and cropping patterns, at the regional experimental station (Ardjasa et al., 2001).

Generally speaking, intercropping cassava cultivation with legume plants could be effective to retain soil fertility. Thus, beneficial intercrops for cassava have been examined for the establishment of a government recommendation in Java Island, Indonesia. Although there is a governmental recommendation for intercropping with legume plants, the technique is not used by the local farmers in Sumatra Island.

We thought that an alternative cultivation system for farmers is required for sustainable crop production in this region. In fact, the productivity of the cassava-based intercropping patterns was not fully tested in terms of the relative importance of cassava density. The root extension growth of cassava may indicate the competition among intercrops when the cassava planting density is different. Therefore, it would be worthwhile to measure the vertical and horizontal extent of cassava roots under different
cropping patterns, which has not been examined so far. Moreover, cassava-based intercropping patterns together with the effectiveness of erosion control have not been thoroughly evaluated in this region. The use of plant residues as in situ mulching material will not only retain the soil fertility but may also reduce soil erosion.

The objective of this study is to compare the productivity among several cassava cropping patterns and to propose the most beneficial cropping for the region. For this purpose, productivity, soil erosion and cassava root extension growth were compared among several cropping patterns with and without mulching.

Materials and Methods

1. Experimental site

In December 1996, an experimental field was established on a gentle slope in Gunung Batin, Lampung State, Sumatra Island, Indonesia (4°45'S, 105°29'E). The slope gradient was approximately 2-4 degrees. The mean annual temperature was 26.9°C with a maximum of 31.9°C and a minimum of 23.1°C. Annual precipitation was 2200 mm, which was concentrated between December and April. The temperature and rainfall during the experimental period are shown in Fig. 1. The 1997 dry season was quite severe, as occurs approximately once every 50-60 years. The soil at the experimental site is classified as Typic Haploxerepts. The soil texture is heavy clay, and the soil chemical properties have been summarized in the series of papers (Sarno et al., 2004).

2. Cropping patterns and mulching treatments

Five cassava based cropping patterns, listed in Table 1, were tested to evaluate the productivity and sustainability. Farmers in this region mainly grow cassava as a sole crop or the intercrops with cereals such as upland rice (Oryza sativa L.) and/or maize (Zea mays L.). For the evaluation of the farmer’s conventional intercropping practice, rice and maize were grown together as the rainy season crop for P3. P1 and P3 were conventional cultivation methods, and P5 was in accordance with the government recommendation. We have introduced P2 and P4 as the possible patterns of crop rotation and intercropping. In P2, crop rotation was conducted in the second year as part of a three-year crop rotation to test whether food cropping without cassava is possible in this district. In this pattern, maize was planted as the first crop, soybean as the second, and cowpea as the third; they were planted sequentially. The size of each plot was 12m × 6m. The planting density (row width × hill distance) of cassava was 20,000 plants per ha (1m × 0.5m) in P1, P2, and P3, and that in P4 and P5 was one half (2m × 0.5m) and one quarter (4m × 0.5m), respectively. Planting densities for other crops are as follows: Maize; 1 m × 0.5 m for P3 and 1 m × 0.25 m for P4 and P5. Rice (line planting, 0.25 m row spacing); 300 rows / ha (36.4 kg dry seeds ha⁻¹) for P3, and 225 rows / ha (27.3 kg dry seeds ha⁻¹) for P5. Soybean and cowpea (0.5 m × 0.1 m); 150 rows / ha for P4, and 175 rows / ha for P5. For P2 in the second year, the row spacing × hill spacing was 1 × 0.25 m for maize (40,000 plants ha⁻¹), 0.5 × 0.1 m for soybean (200,000 plants ha⁻¹) and 0.6 ×
0.4 m for cowpea (125,000 plants ha\(^{-1}\)). All the crops were planted along the contour line. In each cropping pattern, treatments using mulch with plant residuals excluding the cassava stem and without mulch were established. We set up three replications; thus, 30 plots in total were arranged following a randomized complete block design.

### 3. Field management

Maize and upland rice were planted in December, the beginning of the regional rainy season, each year from 1996 to 1998. In January, cassava stem cuttings were planted in all the five treatments. In the intercropping treatments, the cuttings were planted between maize and/or rice rows. After maize and/or rice had been harvested, between April and May, at the end of the rainy season, soybean was planted in the maize and/or rice rows. After soybean had been harvested, cowpea was planted as the dry season crop in July. The total fertilization for each plot for each year is shown in Table 1. This experiment was carried out under a rainfed condition without irrigation. Insect, weed, and pest control for each crop was conducted following the conventional district practices of local farmers.

### 4. Crop yield, soil erosion and economic evaluation

The yield of each crop was determined by harvesting 10 to 20 plants from each plot. For rice, three portions of 1 m line per plot were harvested. The eroded soil was sampled sequentially with a soil collector from February 1998 to August 1999. Simple ditches (0.15 m deep, 0.5 m wide, and 6 m long) were constructed at the lower edge of each plot and were covered with plastic sheeting to collect eroded soils. Samples were collected after each heavy rain. The eroded soil was sun-dried and weighed at each sampling time. A soil subsample was oven-dried to determine the water content. The farm economy was evaluated annually. The net income was calculated with the costs of agricultural inputs and income from the harvested crops. The prices fluctuated significantly within the three years examined due to the foreign exchange fluctuation, especially between 1997 and 1998. These price data were used for the economical analysis. Labor costs were not included in the economic evaluation due to the difficulty of accurate calculation of actual working hours.

### 5. Cassava rooting zone

The size of cassava root system in vertical and horizontal direction was measured in September 1999 at the economically maturing time for cassava in this region. Three replicates of both directions in each treatment were measured. The measurement of root penetration depth was carried out only in P1 with and without mulching and P5 without mulching because of the labor shortage. All the cassava adventitious roots that had emerged from the selected plants were exposed so that the vertical and horizontal extensions could be traced by the measuring tape. The extensions of the cassava root tubers were also measured in both directions. Eight replicates of each treatment were measured.

### Table 1. Five different cassava-based cropping patterns and fertilization rates for each plot.

| Cropping patterns                          | Fertilization rates (kg ha\(^{-1}\) y\(^{-1}\)) |
|------------------------------------------|-----------------------------------------------|
|                                          | N  | P\(_2\)O\(_5\) | K\(_2\)O |
| P1 Cassava monoculture                   | 135| 36          | 120      |
| P2 Crop rotation                         | 135| 36          | 120      |
| 1st and 3rd years, cassava monoculture;  | 180| 90          | 150      |
| 2nd year, food crop sequential pattern of |     |             |          |
| maize→soybean→cowpea.                    |     |             |          |
| P3 Intercropping 1: Farmers practice     | 135| 36          | 120      |
| cassava / (maize + rice)                 |     |             |          |
| P4 Intercropping 2: Newly proposed*      | 180| 72          | 165      |
| cassava / (maize→soybean→cowpea)         |     |             |          |
| P5 Intercropping 3: Government recommendation | 180| 72          | 165      |
| cassava / [(maize + rice)→soybean→cowpea] |     |             |          |

* Planting densities of cassava in P4 and P5 were a half and a quarter of P1, P2, and P3 (20,000 plants per ha, 1 m×0.5 m), respectively. Planting densities for other crops: Maize; 1 m×0.5 m for P3 and 1 m×0.25 m for P4 and P5. Rice (line planting, 0.25 m row spacing); 300 rows / ha for P3, and 225 rows / ha for P5. Soybean and cowpea (0.5 m×0.1 m); 150 rows / ha for P4, and 175 rows / ha for P5.
Light interception

The light intensity in a cassava canopy was measured to evaluate the light competition among the intercrops. The measurements were made on a sunny day in July 1999 during the mid-dry season from 13:00 to 15:00 hours. The light intensity on the top of a soybean leaf in the center row between cassava plants was measured by a photometer. Ten replicates from each plot in P3, 4 and 5 were measured. Within-canopy readings were expressed as a percent of open space readings so as to remove the effects of variation in the cloud cover. Open space readings were made just before and after the measurement inside the canopy of each plot.

Statistical analysis

Two-way analysis of variance (2-way ANOVA) was employed on all the data to verify the effects of the treatment. Furthermore, one-way analysis of variance (1-way ANOVA) and Duncan’s multiple range test were also conducted to compare the means among the treatments.

Results and Discussion

Productivity and economic evaluation

The order of cassava root tuber yield among the five cropping patterns depended basically on the planting density (Fig. 2). The trend, however, varied with the year. In the first year, during a severe drought, cassava single-cropping (P1 and P2) gave the highest cassava yield. In the second year, in which rainfall was moderate, the yield in P4 was identical to that in P1, which could most probably be attributed to the fact that there was less competition for water and nutrients among the intercrops except the drought year. In the third year, P2 gave the highest cassava yield because cassava had not been planted in the previous year. Throughout the experiments, P5 based on the government recommendation showed the lowest cassava yield because the cassava plant density was the lowest. The use of mulch proved to be effective only in the final year, resulting in a yield that was 1.4 times that without mulch. The mulching materials used in this experiment were the plant residues of previous year. Because of severe drought in 1997, residue production was relatively lower in 1997 as compared with that in 1998 with moderate rainfall. This attributed to the significant beneficial effects on ground cover in the final year. Cadavid et al. (1998) suggested that the increase of cassava yield with mulching might be due to the reduction of soil temperature. Although soil temperature was not determined, the residue mulching in 1999 may have resulted in reduced root zone temperature causing higher yield in cassava.

The yield of maize, rice and soybean is shown in Fig. 3. Cowpea did not grow well in the dry season under the rainfed condition in any of the three years; thus, no product was harvested. Soybean was harvested only in the second year because there was a drought in the first year and an outbreak of grasshoppers in the third year. The soybean yield in P4 and P5 was 30 and 50% of that of P2, respectively (food-crop sequential cropping without cassava competition). The maize yield in the second year was the highest of the three years, followed by the third year except in P3. Maize in P3 in the second year was not good due to damage from disease. In the case of rice, an opposite trend was observed. The third year gave the highest yield. The yield in the first year was extremely low because of drought. The effects of mulch on the yield of maize and upland rice was not evident even in 1999, when the effect of mulch was significant in the yield of cassava. The yield of food crops, such as rice, maize, and soybean in P2, P4, and P5, was relatively low. This may be attributed to the low pH and/or dry conditions in the cassava-growing region. Thus, it would not be
beneficial to introduce the food-crop sequential cropping system without cassava in the cassava-production area. However, the soybean shoot growth with mulching (data is not shown) was greater in the final year. During the dry season, mulch may prevent water loss from the soil surface. This should be further analyzed for the possibility of introducing a food-crop system in this area.

The total net income calculated with the sales of crops and the total costs excluding labor are shown in Fig. 4. The net income was the highest for the cassava single-cropping (P1 and P2) in the first year (1.6 million rupiah / ha) because of the stress from the severe drought to the intercrops. The proposed intercropping system (P4) resulted in the highest income (5.2 million rupiah / ha) in the second year of moderate rainfall. In the third year, when there was an outbreak of grasshoppers, the conventional intercropping system (P3) used by the farmers resulted in the highest income. In an average of the three years, the proposed intercropping pattern was most beneficial in terms of farm economy, followed by cassava single-cropping and conventional intercropping used by regional farmers (Fig. 5 upper). Due to the fluctuations in environmental stress, difference between P4 and P1, and between P1 and P3, were not statistically significant. If drought or insect damage were to occur, the cassava single-cropping would be the most beneficial. Although cassava is quite tolerant to drought and insect damage, its price often fluctuates significantly depending on the international market. In fact, in 1997, the first year of the experiment, the cassava price was very low (84 Rp / kg) as compared...
with the second year (160 Rp / kg). In the third year the price was intermediate (110 Rp / kg). In that sense, intercropping with other cash crops should be much safer for farm economy, especially the risk dispersion of cassava low price. This result coincided with that of Benites et al. (1993), who reported that a two-crop system consisting of a legume-non legume intercrop of short-cycle food crops would be worthy of commercial exploitation in a humid tropical environment, although the productivity evaluated with yield or biomass was the highest in a cassava monoculture. Moreover, intercropping with cereal and/or a legume species would be beneficial for weed control to cover the ground, especially before the cassava canopy fully develops (Zuofa et al., 1992; Olasantan et al., 1994).

The government recommendation (P5) was not economically beneficial for any of the three years. This may be attributed to the lower density of the cassava plants, which was one quarter of those of the cassava monoculture (P1) and the conventional method used by the local farmers (P3). Probably, P5 is not a cassava-based but a food-crop-based intercropping system.

2. Soil erosion

The amount of soil erosion was relatively low in the three intercropping systems and food crop rotation compared to the cassava monoculture (Fig. 5 lower). In the intercropping systems, the lower soil erosion was most probably due to the fact that the row spacing of crops was narrower and acted as a hedgerow. Canopy covers by the growth of intercrops would protect the land from direct impact of falling raindrops and would cause a reduction in the erosion. The results of the present study agree with the results of Ardjasa et al. (2001). They reported that cassava cultivation with intercropping of upland rice and maize as the first intercrop reduced soil erosion. Leihner et al. (1996) also found that the erosion in forage-legume intercropping controlled erosion more effectively than cassava single-cropping.

Furthermore, mulching significantly reduced soil erosion. In the series of papers of the present study, Sarno et al. (2004) reported that there was no difference in the content of C and N between the plots with and without mulching with crop residues. The surface mulch resulted in a smaller proportion of clay fraction than that in the plots without mulch, suggesting that mulch affects the maintenance of soil particle distribution. Thus the use of crop residues as surface mulch is recommendable from the viewpoints of soil erosion control. Although mulching has several advantages, it may also be a source of disease and insect pests. It is necessary to pay attention to such negative aspects in the practical use of mulching technique to a cassava multiple-cropping system.

3. Cassava root extension

The intercropping patterns with a different planting density of cassava affected the extension of both root tubers and adventitious roots (Fig. 6). Although the length of cassava root tubers was sometimes analyzed for the tuber productivity (Manrique, 1990; Pinho et al., 1995), root tuber extensions in situ, have not been reported previously. Root tuber extensions, both horizontally and vertically, were significantly restricted in higher-density cassava treatments (P1, 2, and 3) as compared with those in the lower-density treatments of P4 (50% density) and P5 (25% density). Mulching enhanced the tuber development and caused tubers to grow much deeper than they did without mulch.

In this study, vertical root penetration was observed only up to 0.5 m deep in both P1 and P5 (Fig. 7).
Deep root distribution in cassava has been reported in various papers. For example, the deepest cassava roots penetrated to 1 m (Aresta and Fukai, 1984) or even 2.6 m (Connor et al., 1981) in different field conditions and to 1.8 m within three months of planting in a root box (Izumi and Iijima, 2002). In contrast, when cassava was intercropped with legume grass (Muhr et al., 1995) or other grass species (Tscherning et al., 1995), the roots penetrated to 0.5 to 0.75 m. These results are similar to the rooting depths achieved in the present study. As Aresta and Fukai (1984) pointed out, soil strength greatly affects the root distribution. In our experiment, soil mechanical impedance was more than 2.5 MPa at depths of around 15-20 cm during the mid-dry season. Because soil texture was heavy clay, the potential rooting habit of cassava would not be exhibited under such soil conditions. In this experiment, however, adventitious roots extended 1 to 2 m horizontally from the base of the plants. This can be considered to be in compensation for the vertical restriction of the rooting zone. Although the horizontal root distribution in cassava has been reported extensively (Maduakor, 1993; Tscherning et al., 1995; Muhr et al., 1995; Izumi et al., 1999), none of study traced the furthest root tips from the plants. In our study, we found that adventitious root extension depended on the cassava planting density: in comparison with higher-density treatments (P1, 2, and 3), the roots in P4 (50% density) and P5 (25% density) extended 30 and 80% further from the plant.
Table 2. Light interception under a cassava canopy.

| Cropping pattern | Light intensity (μE m⁻² s⁻¹) | Percentage to outside |
|------------------|-------------------------------|-----------------------|
| P3               | 944 ± 194                     | 47.7 a                |
| P4               | 1508 ± 236                    | 73.6 b                |
| P5               | 1740 ± 109                    | 89.7 b                |

Values are shown by mean ± SE. *Reference value was measured outside the plot just before and after the measurement. Same alphabet letters mean no significant difference at P<0.05 level between the cropping patterns according to Duncan’s multiple range test.

base, respectively. The effects of the density of the cassava plants were evident in both root tubers and adventitious root extension.

As for the deepest adventitious root, mulching treatment made it shallower in cassava single-cropping treatment (P1). Opara-Nadi and Lal (1987) reported that the mulching treatment increased cassava root length. If mulch reduces the soil temperature, the environment in the shallower soil of the root zone would be more favorable. Mulching may enhance root development in the shallower zone, and roots with mulch may not penetrate any deeper than those without mulch.

4. Light interception

Light interception under a cassava canopy increased as the density of the plants increased (Table 2). In P3, as the central row of soybean was nearer to the cassava row, light interception increased significantly. As Ikeorgu (1991) and Cenpukdee and Fukai (1992) demonstrated, light interception causes a reduction in the yield of intercrops. Although a cassava canopy strongly reduces the light penetration to the intercropped soybean, it may reduce the transpiration rates of soybean during dry season, which would help the plants to retain the soil water in the rooting zone.

Conclusion

These results lead us to conclude that the proposed cassava intercropping pattern is the most beneficial in terms of economy and risk dispersion; in addition, it reduced soil erosion compared with the cassava single-cropping. Cowpea cultivation as the dry season cropping, however, was not possible in this region. The conventional intercropping methods used by local cassava farmers are also beneficial in terms of reducing the risk of price fluctuation in cassava; however, intercropping with legume species as in the newly proposed or government recommendation should be considered for the sustainable use of cassava field. It would not be beneficial to introduce the food-crop sequential cropping system without planting cassava as shown in the result of P2 second year.

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