Maize-Soybean-Cowpea Sequential Cropping as a Sustainable Crop Production for Acid-Infertile Clay Soils in Indonesia

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Abstract: At mid-elevation terraces in the southern part of Sumatra Island, Indonesia, cassava is widely cultivated as one of the most important cash crops for farmers. However, the prominent cassava cultivation system includes the intercropping of cereal crops and rapidly depletes soil fertility. Hence establishment of a sustainable food-crop production system without cassava cultivation is required. A three-way experiment with maize-soybean-cowpea sequential cropping was designed to investigate the following main effects: tillage or no-tillage, mulching or no-mulching and government recommendation or farmers’ traditional fertilization. Crop productivity and soil erosion were used as indicators of sustainability. At the end of the experiment, root system development of soybean was assessed to elucidate the cumulative effects of treatments on the soil environment for root growth. Fertilization treatments increased yields in all years, whereas mulching significantly increased only from the third year. The no-tillage treatment tended to reduce yields. Soybean root growth at surface level was markedly reduced by no-tillage and slightly improved by mulching. Erosion was reduced by mulching, no-tillage, and fertilization by the government recommendation. Because of its cumulative effect on increasing soil fertility and reducing erosion, the practice of mulching was highly recommended. A sufficient amount of fertilization (government level) was also recommended to maintain the fertility and to support sufficient plant growth to minimize erosion. The no-tillage practice was not recommended because it reduced crop yields, although the treatment efficiently controlled soil erosion.

Key words: Cowpea, Erosion, Maize, Mulching, Red acid soil, Root growth, Soybean.

In Gunungbatin of Lampung State, located in the southern part of Sumatra Island, Indonesia, cassava is widely cultivated at mid-elevation terraces as one of the most important cash crops for farmers. The prominent cassava cultivation system includes the intercropping of cereal crops, and this combination rapidly depletes soil fertility. The farm economy is also unstable due to significant fluctuations of the price of cassava. Furthermore, the common red acid Acrisol soils in the region are low in fertility and vulnerable to erosion and degradation (Lumbanraja et al., 1998; Iijima et al., 1999; Iijima et al., 2003). Hence, the government has recommended alternative legume-based cropping systems that help retain soil fertility and enhance sustainability (Arjasa et al., 2001).

In a related study (Iijima et al., 2004), we examined the productivity of crop rotation systems where food crop was alternated annually with a cassava monoculture. A single, year-long trial of maize (Zea mays L.) - soybean (Glycine max (L.) Merr.) - cowpea (Vigna unguiculata (L.) Walp.) sequential cropping was evaluated as one of five cassava-based cropping systems. In the year after this food-crop sequential pattern, the highest cassava yield among the cropping patterns examined (monoculture system and/or intercropping with cereal crops) was recorded, indicating that this sequential cropping system was effective for sustaining productivity. In this study, the three-year food-crop sequential cropping without cassava cultivation was further studied with a combination of cropping techniques.

No-tillage practice is already well known to be effective for soil erosion control. For example, it significantly reduced soil erosion under maize-cowpea sequential cropping in Nigeria (Lal, 1997). Similarly, surface mulching with residues from previous crops is reportedly effective for reducing erosion (Fischer et al., 2002b) and restoring and improving the productivity of soils in the humid tropics (Ogban et al., 2001). By covering the soil surface mulching also lowers soil temperature and reduces water loss (Cadavid et al., 1998; McGonigle et al., 1999). Furthermore,
Ghuman and Sur (2001) suggested the use of residue mulch in conjunction with minimum tillage in order to improve soil quality and sustain/improve crop production. Thus, we conducted a field experiment with maize-soybean-cowpea sequential cropping to test the main effect and interaction of no-tillage and mulching on sustainability. A fertilization treatment was included as a third factor because it can affect sustainability via the plant nutrient status itself and via the biomass production, and can also interact with the other two factors. Crop productivity and soil erosion were compared between tillage/no-tillage, mulching/no-mulching and two fertilization levels over three years. At the end of the experiment, the root system of soybean was assessed to determine the cumulative impact of treatments on the soil environment for root growth. The objective of this study was to determine the potential of sequential cropping as a sustainable food-crop production system in the red acid soil region in Indonesia. Changes in the soil properties due to experimental treatments have been reported elsewhere (Sarno et al., 2004).

**Materials and Methods**

1. **Site descriptions**

   This experiment was conducted from December 1996 to July 1999 on a gentle slope located in Gunungbatin, Lampung State, Sumatra Island, Indonesia (4°45’S, 105°29’E). The soil at the experimental site, classified as Typic Haploxerepts, has a heavy clay texture and a pH (H₂O) of 4.6. In 1997, conditions were extraordinarily dry; annual rainfall was 1247 mm, which was almost half of that in 1998 (2540 mm). In 1999, there was abundant rainfall during the experiment (1860 mm from January to September). Further detailed information concerning the soil properties and climate conditions at the field has been published elsewhere (Iijima et al., 2004; Sarno et al., 2004).

2. **Experimental design**

   A three-way experiment was designed. Treatment of the main plots was as follows: tillage (farmers’ tradition) or no-tillage (government recommendation); no-mulching (farmers’ tradition) or mulching with plant residues (government recommendation); and two levels of fertilization, i.e., level recommended by government (government recommendation hereafter) or a reduced dosage simulating the farmers’ tradition (farmers’ fertilization hereafter). Therefore, eight treatment plots combining the three factors were arranged following a randomized complete block design with three replications. The size of each plot was 72 m² (12 × 6 m), and these treatments were continued for each plot throughout the experiment. In the tillage treatment, the field was tilled manually just before the sowing of each crop and for weeding on demand. In the no-tillage treatment, the field was not tilled throughout the experiment except where planting holes were made, and chemical herbicides were used for weeding. For the mulching treatment, plant residues of the previous crop were placed over the soil surface. In the no-mulching treatment, all residues were removed from the field. All fertilization was done as a basal dressing using urea, superphosphate, and KCl (Table 1). Combined amount of fertilizer for maize, soybean and cowpea during a year in the farmers’ fertilization is half the government recommendation for N and P₂O₅ and three-fifths of it for K₂O.

3. **Field management**

   Maize (cv. Bisma), soybean (cv. Willis), and cowpea (cv. Kacang Tungah) were planted sequentially (Table 2). In the first year, when a severe drought caused by “El Niño” occurred, there was no rainfall between August 7 and October 6, so that cowpea was not planted. In the last year, the experiment was completed at the shoot sampling of soybean on July 16-17. The row spacing x 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

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**Table 1. Amount of fertilizer applied (kg ha⁻¹) by government recommendation and farmers’ tradition for each year.**

| Level       | Crop       | N | P₂O₅ | K₂O |
|-------------|------------|---|------|-----|
| Government  | Soybean    | 45 | 45   | 60  |
|             | Cowpea     |   |      |     |
| Farmers’    | Soybean    | 90 | 45   | 90  |
|             | Cowpea     |   |      |     |

**Table 2. Sowing and harvesting dates in the experiment.**

| Year       | Crop       | Sowing    | Harvesting  |
|------------|------------|-----------|-------------|
| 1st        | Maize      | Dec. 27   | Apr. 19     |
|            | Soybean    | May 22    | Aug. 15-18  |
|            | Cowpea     | Not planted|            |
| 2nd        | Maize      | Dec. 11   | Apr. 20-21  |
|            | Soybean    | May 25-26 | Aug. 22     |
|            | Cowpea     | Sep. 3    | Nov. 3-6    |
| 3rd        | Maize      | Nov. 10   | Feb. 11-15  |
|            | Soybean    | May 3     | Jul. 16-17  |
|            | Cowpea     | Not planted|            |

*In the third year, soybean was harvested before maturing stage.*
(125,000 plants ha\(^{-1}\)). No irrigation was applied during the experiment. Insect, weed, and pest control for each crop was conducted following the conventional district practices of the local farmers.

4. Data collection and analysis

At the harvest of each crop, 10 to 20 plants were selected from each plot and air-dried to determine the total biomass (shoot dry weight) and grain yield (seed weight). Soybean root growth was assessed for 75-day-old plants using the core sampling method (Böhm, 1979). On July 17, 1999, a 40-cm deep trench was excavated first below the interrow space (5 cm apart from the row) and then just below the row. Soil samples were taken at depths of 2.5-7.5 cm, 12.5-17.5 cm, 22.5-27.5 cm, and 32.5-37.5 cm using a stainless steel core sampler with inner diameter and volume of 5 cm and 100 cm\(^3\), respectively. After removing the soil and debris by washing with tap water, the root fresh weight was measured, and the root weight density, i.e., the root weight per unit of soil volume, was calculated. The eroded soil was sampled after each heavy rain event. Simple ditches (0.15-m deep, 0.5-m wide, and 6-m long) were constructed at the lower edge of each plot in one of the three replications and covered with plastic sheeting to collect the eroded soil. The sampled soil was sun-dried and weighed at each sampling. A soil sub-sample was oven-dried to estimate the water content. To verify the effects of the treatment, we performed a three-way analysis of variance (3-way ANOVA) on the biomass and grain yield of the crops and the root weight density of soybean. When evaluating erosion, year was included as an additional factor for statistical analysis because no replication was used.

Results and Discussion

1. Crop Productivity

A significant main effect of fertilization treatment was found throughout the experimental period for both biomass production and grain yield of the crops (Table 3). A significant main effect of tillage was observed in soybean yield in the first year, maize and cowpea biomass and maize yield in the second year and in soybean biomass in the third year. The effect of mulching was not significant in the first and second years, but a significant main effect of mulching was observed in the third year with a significant interaction (P<0.1) of tillage × mulching.

The grain yields of maize, soybean, and cowpea were relatively low, probably due to the low soil pH, even though a sufficient amount of fertilizer had been
supplied following the government recommendation (Table 4). Lime application to modify the soil acidity is not recommended by the local government because it may cause soil hardening in this region. The grain yield of maize was relatively stable for two years, but declined marginally in the third year due to severe damage caused by a grasshopper plague. In the second year, the maize yield was lower (P<0.1) without tillage than with tillage treatment. In the third year, a significant increase in the grain yield occurred with the fertilization treatment differences in yield were relatively small, as pointed out by Torbert et al. (1998). This trend was also found in the biomass of maize and soybean in the third year (data not shown). Hence, this result suggests that the tillage practice is necessary to effectively incorporate nutrients and organic matters from plant residues into the soil.

The no-tillage practice tended to produce lower biomass and grain yield in several crops and years and in no cases improved yield (Table 3). A cumulative effect of continuous no-tillage practice on the improvement of the soil conditions for plant growth has been previously reported (Hammel, 1989; Izumi et al., 2004). However, Sims et al. (1998) suggested that tillage might be necessary to maintain optimum maize production levels on fine-textured soils. Rembon and MacKenzie (1997) reported that, in a maize-soybean rotation tillage, the effects on the nitrogen contribution of soybean to maize differed between sites but could not be related to the tillage practice or the soil type. Hussain et al. (1999) reported that a no-tillage system produced higher maize and soybean yields in dry years. The results of the present study, however, indicate that a continuous no-tillage practice is not suitable for crop production in these heavy clay, red acid soils of low inherent fertility. Fischer et al. (2002a) reported that the combination of zero tillage and residue retention was especially favored during dry

### Table 4. Effects of tillage, mulching and fertilization on the grain yield of the crops (kg ha$^{-1}$) for three years.

| Treatment | Maize$^a$ | Soybean$^a$ | Cowpea$^a$ |
|-----------|-----------|-------------|------------|
|           | 1st$^b$   | 2nd         | 3rd        | 1st        | 2nd         | 2nd        |
| Tillage   | 1148      | 1184        | 871        | 194        | 528         | 556        |
| No-tillage| 1225      | 976         | 708        | 159        | 486         | 497        |
| Mulching  | ns        | ↑           | ns         | ↑          | ns          | ns         |
| No-mulching| 1085     | 606         | 177        | 465        | 515         |            |
| Farmers'  | 806       | 948         | 378        | 156        | 393         | 466        |
| Government| 1566      | 1212        | 1200       | 198        | 621         | 587        |

***, ** and *: significantly different at P<0.001, 0.01, 0.05 and 0.1 level, respectively; ns: not significantly different (P≥0.1).  
$^a$: See footnotes in Table 3.
seasons for sustaining the soil resources but perhaps disadvantaged in wet ones. This can partly explain the negative or ineffective results of the no-tillage treatment in our experiment, which was conducted under relatively wet conditions with the exception of the first year.

2. Soybean root growth

The effect of continuous tillage, mulching, and fertilization for three years on the root system development of soybean is summarized in Fig. 1. In the no-tillage treatment, the root weight density was significantly lower compared to the tillage treatment in the 5-cm layer (Fig. 1a) and the inhibited root growth near the soil surface caused a reduction in shoot biomass. The higher soil bulk density in the no-tillage treatment may have reduced soil water storage due to the reduced pore space leading to lower crop yields during dry year. Chassot et al. (2001) mentioned that the increased bulk density of topsoil resulting from the no-tillage practice restricted the root growth of maize more markedly in soil with a finer texture and that such soil must be tilled more intensively. On the other hand, the root distribution of soybean near the soil surface is often more abundant without tillage than with conventional tillage (Lal, 1989; Oyanagi et al., 1998). In crop rotations combining maize and soybean, Holanda et al. (1998) reported that no-tillage resulted in a higher rate of root growth in silty clay loam soil. In a wheat-soybean rotation conducted in Japan (Izumi et al., 2004), continuous no-tillage lowered the mechanical impedance in the deeper layer of a light clay soil, and resulted in an improvement of soybean root growth. Therefore, it may be concluded that continuous no-tillage reduced root growth at the soil surface and that deep tillage is required to maintain the productivity of this heavy clay, red acid soil.

Conversely, a significant improvement in root growth due to the mulching treatment was found in the 15-cm layer (Fig. 1b). The effect of residue cover on root growth due to increased plant available soil water (PASW) in the near-surface soil zone has been reported in wheat (Merrill et al., 1996) and maize (Gill et al., 1996). In this study, a non-significant trend towards higher root weight density in the 5-cm layer of the mulching treatment suggests a response similar to mulching. Furthermore, increased carbon and nutrient supply from plant residues are reported to ameliorate the soil condition for root growth (Sarno et al., 2004). In their study the use of surface mulch resulted not only in higher available P concentration but also in less clay fraction in soil than without mulching. The proportion of clay in soil with and without mulching was 19.9 and 22.7%, respectively, suggesting the effect of mulching on the maintenance of soil particle distribution. Moreover, a significant tillage × mulching interaction was observed. The root weight densities at 15-cm layer in the tillage with mulching, tillage with no-mulching, no-tillage with mulching, and no-tillage with no-mulching combinations were 1.69, 1.08, 1.30, and 0.99 mg cm$^{-3}$, respectively, so that the effect of mulching is greater with tillage than without tillage, as discussed in the previous section.

Although the root weight density in the surface layer was slightly higher with fertilization by the government recommendation than by the farmers’ tradition, no significant difference between the treatments existed.
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(Fig. 1c). It was not clear why the fertilization level did not greatly affect the soybean root growth in spite of the significant difference in shoot growth. Luxury level of fertilized nitrogen to limit soybean root growth by the government recommendation might be the reason.

3. Soil erosion
The collection of eroded soil was started from the middle of 1997. Due to a severe drought, almost no erosion occurred in the last part of that year so that sampling of eroded soil started from the second year. The amount of erosion (Table 5) was significantly reduced by the no-tillage (−31%), mulching (−12%), and fertilization by government recommendation (−17%). Furthermore, a significant tillage × mulching interaction was observed (P<0.05). The monthly erosion levels in the tillage with mulching, tillage with no-mulching, no-tillage with mulching, and no-tillage without mulching combinations were 3.1, 4.0, 2.5, and 2.4 ton ha⁻¹, respectively. This suggests that the erosion in a tilled field is substantially reduced by mulching. In other experiments conducted in red acid soil regions in Lampung State, erosion control was also achieved by no-tillage (Iijima et al., 2003) and mulching (Iijima et al., 2004). Fischer et al. (2002b) reported that runoff during rain events was negligible where crop residue was retained on the surface with zero tillage in sub-humid tropical highlands. Hence, by continuing the no-tillage and mulching practices, it is expected that erosion control will be more evident later by the cumulative effects of each as well as by a synergistic effect of both. Fertilization by government recommendation also resulted in less erosion as compared to that by the farmers’ tradition probably due to the larger biomass production improving soil cover during the cropping season and the residue for mulching during the next crop.

4. Conclusion
In this experiment, the cumulative effect of mulching using residues from the previous crop maintained soil fertility and reduced soil erosion in a maize-soybean-cowpea sequential cropping system. This practice is therefore highly recommended for sustainable food-crop production in the red acid soil regions of Sumatra, Indonesia. Application of a sufficient amount of fertilizer (e.g., the government recommendation) is also recommended to maintain soil fertility and to provide sufficient plant growth for maximum soil protection. No-tillage is not recommended from the viewpoint of crop production but is desirable for erosion control.

Although the combination of tillage, mulching and fertilization by government recommendation (TMG) produced the highest crop yield and root growth for soybean, the combination of no-tillage, mulching and fertilization by government recommendation (nTMG) supported high yields and excellent erosion control and was expected to maintain soil fertility through mulching (Table 6). Therefore, this combination is likely to be accepted by local farmers on condition that the merit of no-tillage in saving time and cost for tillage practice is greater than alternative herbicide application.

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