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CASSAVA LEAF LITTER ESTIMATION IN ON-FARM TRIALS

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SUMMARY

Cassava (*Manihot esculenta*) returns organic matter and nutrients to the soil through leaf litter and these amounts need to be quantified to help understand and design sustainable cropping systems. Our objectives were to estimate dry matter and nutrient contents in cassava leaf litter and to derive relationships between litter fall and easily measurable cassava yield components. Litter traps (1 m^2) were placed in farmers' fields for monthly monitoring during a three year period. Maximum monthly leaf litter production ranged from 0.5 to 1.0 t ha^{-1}, and occurred at the end of the first rainy season and at the onset of the next rainy season. In the first year, the mean dry matter of leaves collected during 12 months of growth was 3.4 t ha^{-1} for the unamended treatment, and 4.1 t ha^{-1} when N-P-K fertilizer was applied. The totals were 2.4 and 3.0 t ha^{-1} in 2000–2001 and 1.6 and 2.5 t ha^{-1} in 2001–2002, respectively. Annual differences were apparently related to rainfall. The relationship with fresh root yield was best described using one slope and yearly intercepts giving an r^2 of 0.63. This relationship can be exploited for estimating litter dry matter in agronomic experiments when rough estimates are sufficient, keeping in mind that the relationship may not be the same for cultivars of differing architecture. Otherwise, the use of litter traps gives the best estimate of annual litter production.

INTRODUCTION

Organic matter is a key component of tropical soil determining its productivity and structural integrity (Pieri, 1989; Young, 1989; Feller, 1995; Carsky *et al.*, 1998). Crop residues can be an important source of soil organic matter in cropping systems (Poulain, 1980). In cassava, the roots and a portion of the stems are harvested, the latter for planting material. Therefore living and dead leaves are normally the only remaining input to the soil carbon and nutrient balance in cassava cropping. These should be taken into account in modelling the changes in soil carbon in the search for sustainable cropping systems.

Leaf litter of cassava has been found to be an important source of organic matter and nutrients. Although Howeler and Cadavid (1983) did not measure litter production they did state that new leaf production was offset by leaf fall after the fourth month of growth. Van Noordwijk and Purnomisid (1992) estimated that 2 to 2.5 t ha^{-1} of fallen leaves were produced in nine months of growth in a humid zone of Indonesia. Kühne (1993) collected approximately 1.4 t ha^{-1} in unamended plots and 3.1 t ha^{-1} in plots receiving NPK fertilizer in the subhumid zone of southern Benin. This may partly explain why Saragoni *et al.* (1992) observed higher than normal yields of maize

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immediately after a cassava crop in southern Togo. Indeed, farmers in southern Benin plant a dense stand of cassava with a perception that it regenerates degraded soil (Hinvi *et al.*, 1992). Pellet and El-Sharkawy (1997) found up to 3.0 t ha^{-1} of leaf litter at harvest for four varieties grown for ten months in Colombia. The litter contained approximately 30 kg N, 2 kg P and 5 kg K ha^{-1}. Two objectives of this study were (1) to confirm the substantial quantities of leaf litter in farmers' fields as a source of organic matter and (2) to test the effect of fertilizer application on leaf litter production.

The amount of litter produced by cassava is rarely determined. This is because it is necessary to collect the leaves before they fall and become contaminated by soil. Attached particles of soil are heavy relative to the leaves and therefore can cause overestimation of litter dry matter and underestimation of nutrient concentrations. Van Noordwijk and Purnomisid (1992) solved this problem by removing yellow leaves every two to three days, assuming that these would soon fall as litter. A possible solution might be to count leaf scars, but this would only be useful if the weight of individual leaves is constant throughout the year. Another solution is to install traps to catch litter before it reaches the ground. Kühne (1993) used litter traps to collect fallen leaves on a weekly or monthly basis and estimated that litter represented 37 % of above ground dry matter of cassava variety TMS 30572. This ratio was used by other researchers such as Akondé *et al.* (1996) to estimate cassava litter production from above ground dry matter. However most researchers measure fresh root yield, and its relationship with litter dry matter has not been reported.

Therefore, while it is important to estimate leaf litter in cassava, it requires considerable human or material resources and thus is rarely done, especially in on-farm trials that are often located far from each other. It would be useful to derive relationships between cassava production and litter fall, thus allowing researchers to gain useful information with less expense. The function derived by Kühne (1993), relating litter fall to total above ground dry matter, was based on data derived from one cassava variety at one site during two years in southern Benin. We hypothesized that it is possible to derive a function linking litter fall to easily measurable cassava yield components using the variability encountered on a range of farmers' fields over a three year period. A third objective was therefore to derive transfer functions to estimate litter production in cassava.

MATERIALS AND METHODS

Trials were conducted on farmers fields at Hayakpa, Benin (2°08′E, 6°33′N; approx. 150 m asl). The rainfall pattern is bimodal with very little rain expected from 15 November to 15 April and again from 15 July to 15 August. Upland agriculture and traditional human settlement in southern Benin and Togo is concentrated on low-lying plateaus with deep soils (locally known as *terre de barre*) formed on Quaternary sediments. The soils are classified as Ferrali-Haplic Acrisols (Stahr *et al.*, 1996) or *sols ferralytiques moyennement désaturés appauvris* (Raunet, 1977). They have sandy loam topsoil and sandy clay to clay subsoil and they are slightly acid in the surface layer and acid in the subsoil. In the trial fields, organic carbon content in the top 0.3 m was 10 g kg^{-1}

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(*s.d.* 1.3 g kg^{-1}); Bray-1 P was 6.7 mg kg^{-1} (*s.d.* 1.6 mg kg^{-1}) and exchangeable K was 0.13 cmol kg^{-1} (*s.d.* 0.04 cmol kg^{-1}). Rainfall was measured daily at two sites in the village within 5 km of each farmers' field. The cumulative rainfall from the average of the two rain gauges during the cropping period was high (1379 mm) in 1999–2000, low (908 mm) in 2000–2001 and very low (670 mm) in 2001–2002.

Three successive cassava crops were planted on 15 farmers' fields dispersed over one village territory (10 km diameter) between mid-May and early June in 1999, 2000 and 2001. Each field had six plots with the same six fertilizer treatments including an unamended control (called 0-0-0) and complete fertilizer (N-P-K). The fertilizer treatments were repeated on the same plots each year. Litter traps were placed in the 0-0-0 and N-P-K plots in ten of the 15 fields during 1999–2000 and all 15 fields in 2000 and 2001. Fertilizer application rates were 60 kg N ha^{-1} as urea, 16 kg P ha^{-1} as triple superphosphate and 138 kg K ha^{-1} as muriate of potash. Plot size was 10×10 m. The variety used (BEN 86052) is erect and forms two sympodial branches at each fork (INRAB, 1995). No information is available on leaf retention and leafiness. Stem cuttings of 0.20 m length were planted at an angle at a spacing of 1.0×1.0 m. Plots were kept weed-free throughout the cropping cycles. There was some competition apparent between cassava and the surrounding fallow vegetation but this was avoided by shifting harvest areas away from the affected rows.

Litter traps were constructed using a wooden frame with dimensions of 1.25×0.8 m holding mosquito netting at 0.01 m above the soil surface and a 0.01 m high wooden border. The area dimensions were designed to avoid damage to cassava while installing the traps. Traps were always placed in the same orientation with respect to each treatment. In 1999 the traps were placed in plots five weeks before litter collection was to begin. Litter was then collected every month from five months after planting (MAP) until harvest at 12 MAP. In 2000 and 2001 the litter traps were installed at three MAP and litter was collected every month from four MAP until harvest at approximately 11 MAP. At each sampling date, the leaves (plus petioles) were counted and then dried in a forced draft oven at 65 °C for three to four days. The nutrient (N, P, and K) concentration of litter was determined in samples collected at nine MAP by the Analytical Services Laboratory of IITA. There were some missing data in the first and third year, so the year effect on litter nutrient concentration could not be tested. The fresh weight of cassava roots was measured at harvest when between 24 and 48 plants were sampled. At least three plants were separated into root, stem and leaf and weighed before and after oven-drying.

The dry mean mass of litter per trap (1 m^2) was calculated at each sample date. ANOVA was used to compare the fertilized and unamended treatments at each sample date and cumulatively for the entire period of collection. The mean weight per leaf was also calculated each month and the fertilizer effect was tested at each sample date. The cumulative litter dry mass at harvest was calculated as well as the ratios of cumulative litter DM to cassava total DM (above- and below-ground dry matter, not including litter), above-ground DM (not including litter), root DM, and root fresh weight for each season. These variables were also subjected to ANOVA using Proc GLM in SAS to test the fertilizer effect (SAS Institute, 1985).

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The nutrient content of litter was calculated using the average nutrient concentrations over the three seasons and assuming that values at nine MAP were representative of the period during which litter was produced. Howeler and Cadavid (1983) found that N, P, and K concentrations of upper leaves and stems were relatively constant from 6 to 12 months after planting. The effect of fertilizer on litter nutrient content was only taken into account for K.

Cumulative litter production at harvest was regressed on total DM, total above ground DM, root DM, and root fresh weight as predictors for each growing season allowing a positive intercept. A heterogeneity of slopes model was tested (with Proc GLM in SAS with years as classes) to see if the slope varied significantly over the years. The model was: Cumulative Litter DM = PREDICTOR + Year + PREDICTOR * Year. If the interaction term was not significant, then the common slope was estimated by deleting the interaction term and using the 'solution' option that gives the intercept for each class (year). Proc GLM does not give standard errors of the intercepts so the model was run using Proc REG by creating a dummy variable for each year. Subsequently, the correlation between the intercept and the annual rainfall was calculated.

RESULTS

The dry mass of cassava litter accumulated per month is shown in Figure 1. In 1999–2000, litter production was affected by the fertilizer application treatments only in the fifth MAP. The highest monthly litter amounts of approximately 800 kg ha^{-1} were produced from October to December when the plants were developing rapidly (5 to 7 MAP) and soil moisture was adequate (the end of the rainy season). Amounts less than 100 kg ha^{-1} were produced in March/April followed by rapid increases as the rains began in April/May. In 2000–2001, the peak came in December (about 700 kg ha^{-1}) and amounts were lower during the dry season. When the rains established in April to May the litter production exceeded 1 t ha^{-1} on the fertilized plots. In 2001–2002, the annual pattern was similar to 2000–2001 but with a smaller amplitude. The effect of fertilizer amendment on monthly litter dry matter was evident in most months. The peak again came in December, reaching 0.5 t ha^{-1} on the amended plots. Dry season litter production was slightly higher than in the two previous years, especially on the amended plots, because of sporadic rains during the dry season (Figure 1).

The weight of individual fallen leaves is shown in Figure 2. In 1999–2000, leaf weight was approximately 1 g at 5 MAP and decreased steadily reaching a minimum of less than 0.3 g in April. In 2000–2001, leaf weight again peaked at approximately 1 g at 5 MAP and then decreased to less than 0.3 g in March to April. Fallen leaves were significantly ($p < 0.05$) heavier in the amended plots in five out of nine months. In 2001–2002, maximum leaf weight was 0.8 g and minimum leaf weight was never below 0.4 g. The effect of fertilizer on leaf weight was significant in eight out of nine months. In all years, the weight of fallen leaves increased with the first rains in April/May.

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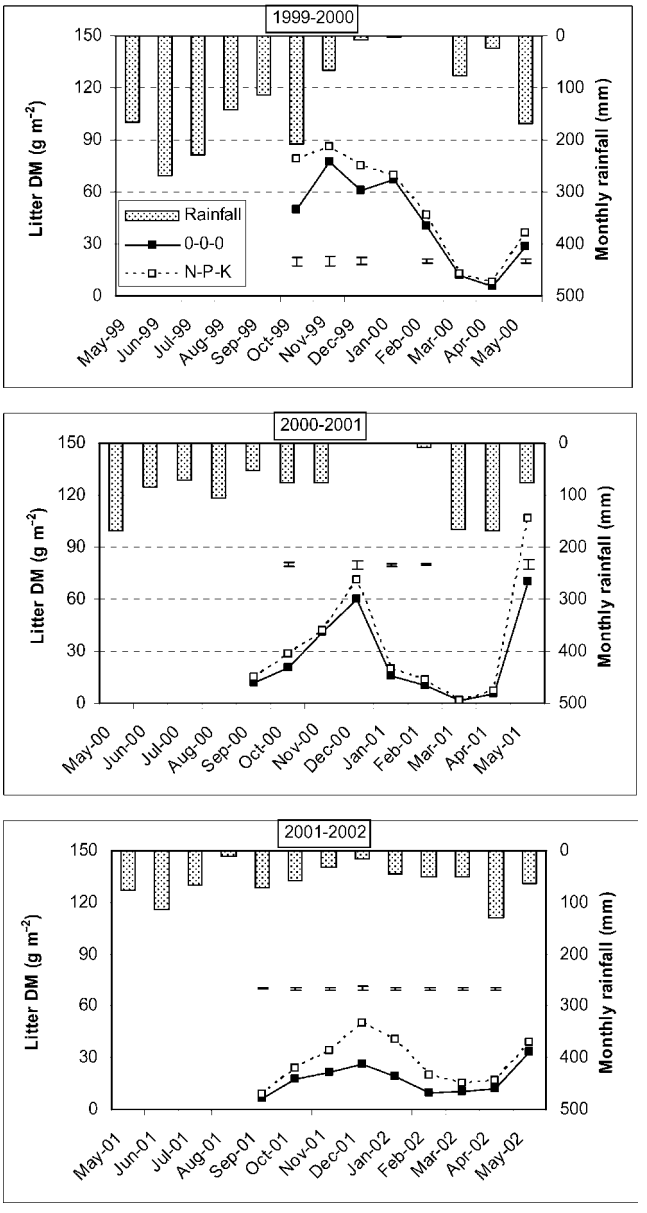


Figure 1. Monthly rainfall and cassava litter dry matter (DM) production on 10 (1999–2000) and 15 (2000–2001 and 2001–2002) farmers' fields for three one-year cassava cropping cycles. Error bars represent standard errors of mean monthly litter DM.

Cumulative litter DM produced without fertilizer application was 3.4 t ha^{-1} in 1999–2000, 2.35 t ha^{-1} in 2000–2001, and 1.55 t ha^{-1} in 2001–2002 (Table 1). It was significantly increased by fertilizer application each year. The increase due to fertilizer application was 21 % in the first year, 30 % in the second and 60 % in the third.

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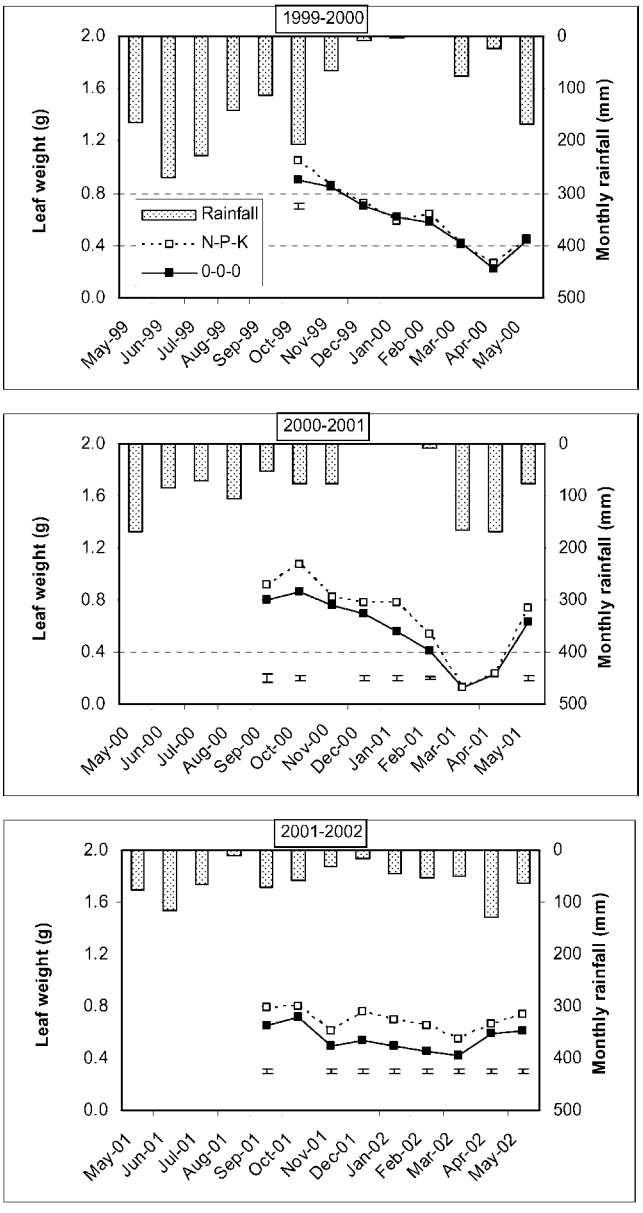


Figure 2. Monthly rainfall and mean dry matter (DM) leaf weight (g leaf^{-1}) on 10 (1999–2000) and 15 (2000–2001 and 2001–2002) farmers' fields for three one-year cassava cycles, with or without fertilizer. Error bars represent standard errors of mean monthly litter leaf weight.

The production of litter as a percentage of production of total DM, above-ground DM, root DM and root fresh weight was not influenced by fertilizer (Table 1). The mean ratio of litter to total dry matter (excluding litter) was 29 % in 1999–2000, 25 % in 2000–2001 and 28 % in 2001–2002. The range divided by the lowest value (relative

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Table 1. Cumulative cassava litter fall dry matter (DM) and selected ratios, during 12 months on 10 (in 1999–2000) and 15 (2000–2001 and 2001–2002) farmers' fields in southern Benin, with and without fertilizer.

Year	Fertilizer treatment	Litter DM (t ha^{-1})	Litter DM as % of:			
			Total DM†	Above-ground DM‡	Root DM	Fresh root
1999–2000	0-0-0	3.40	28.0	62.4	54.0	17.7
	N-P-K	4.12	30.1	59.1	65.1	20.2
	s.e.	0.14	2.54	7.70	3.86	1.33
2000–2001	0-0-0	2.35	23.5	53.5	42.9	14.8
	N-P-K	3.05	25.9	59.9	46.9	15.6
	s.e.	0.11	2.08	6.28	3.15	1.09
2001–2002	0-0-0	1.55	29.2	87.0	44.9	14.4
	N-P-K	2.48	27.2	81.9	41.5	12.0
	s.e.	0.11	2.08	6.28	3.15	1.09

† Litter DM divided by root, leaf and stem DM.
‡ Litter DM divided by leaf and stem DM.

Table 2. Annual cumulative cassava litter fall dry matter (DM) as a percentage of cassava yield (mean of fertilized and unfertilized treatments) and relative ranges.

Year	Litter as			
	% of total DM†	% above-ground DM‡	% of root DM	% of fresh root
1999–2000	29.0	60.8	59.5	19.0
2000–2001	24.7	56.7	44.9	15.2
2001–2002	28.2	84.4	43.2	13.2
Relative range (%)	17	49	39	44

† Litter DM divided by root, leaf and stem DM.
‡ Litter DM divided by leaf and stem DM.
Relative range = (highest value − lowest value)/lowest value.

range) was 17 %, indicating a relatively constant value (Table 2). The other ratios suggest substantially more variability with relative ranges of 49 % for above ground dry matter, 39 % for root dry matter and 44 % for root fresh weight.

Of all the predictors of annual litter DM, the fresh root yield gave the best fit each year and for all three years combined, although the relationships varied with years as shown in Table 2. Relationships between cumulative litter dry matter and fresh cassava root yield are depicted for the three years of the study in Figure 3. From the slopes of the regression lines it can be seen that a 1 t ha^{-1} increase in fresh root yield was associated (within the limited ranges of yield) with increases of litter dry matter of 0.087 (*s.e.* 0.028) t ha^{-1} in 1999–2000, 0.103 (*s.e.* 0.042) t ha^{-1} in 2000–2001 and 0.066 (*s.e.* 0.014) t ha^{-1} in 2001–2002. These slopes are all significantly different from a horizontal line but the relationships are not strong, as indicated by the r^2 values less than 0.5.

The PREDICTOR*Year interaction term was not significant for fresh root yield and root DM as predictors. Therefore, the interaction term was removed from the

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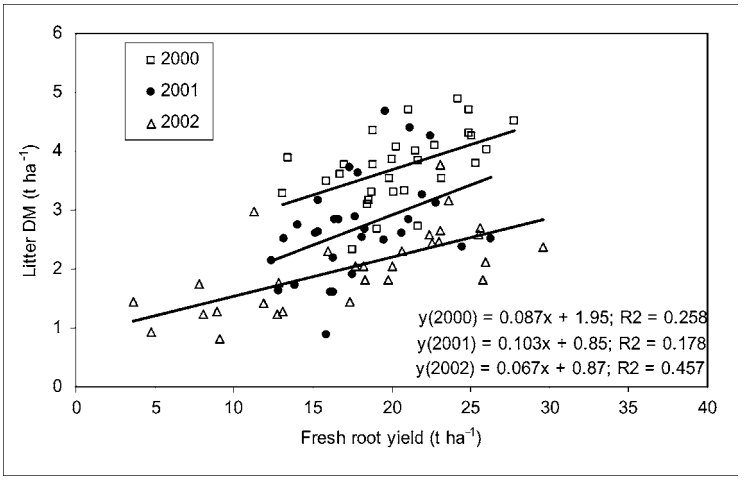


Figure 3. Relationships between cumulative leaf litter dry matter (DM) production over 12 months of growth and fresh root yield on 10 farmers' fields in 1999–2000 and 15 fields in 2000–2001 and 2001–2002. The combined data set has a common slope of 0.076 t t^{-1} and intercepts of 2.18 t ha^{-1} for 1999–2000, 1.34 t ha^{-1} for 2000–2001, and 0.7 t ha^{-1} for 2001–2002.

Table 3. Effect of fertilizer application on mean nutrient concentration (g kg^{-1}) of cassava leaf litter at 9 monhs after planting for three years combined.

Fertilizer treatment	N	P	K
0-0-0	22.2	1.25	5.4
N-P-K	21.4	1.20	7.0
s.e.	0.39	0.07	0.47
n	71	58	73

model (resulting in only root yield and years as terms) giving a common slope of 0.076 (*s.e.* 0.013) t litter DM per tonne of fresh roots and an r^2 of 0.63 for the common slope and the three intercepts model. This is an improvement over the relationships for the three individual years. The model might be used for predictive purposes depending on the precision required. The annual mean cumulative litter DM was significantly different as shown by y-axis intercepts of 2.18 (*s.e.* 0.30) t ha^{-1} in 2000, 1.34 (*s.e.* 0.27) t ha^{-1} in 2001 and 0.7 (*s.e.* 0.26) t ha^{-1} in 2002 (data not shown). These intercepts are related to annual rainfall with a correlation coefficient of 0.994 (data not shown). For root DM, the common slope was 0.226 (*s.e.* 0.044) t litter DM per tonne of fresh roots and an r^2 of 0.61 for the common slope and the three intercepts model. The intercepts were 2.25 (*s.e.* 0.31) t ha^{-1} in 2000, 1.33 t ha^{-1} (*s.e.* 0.29) in 2001 and 0.84 (*s.e.* 0.26) t ha^{-1} in 2002. The total DM and above ground DM had significant PREDICTOR*Year terms, indicating that yearly slopes were heterogeneous.

The nitrogen and phosphorus concentration of the litter at nine MAP was not affected by fertilizer application over the three years of the study. Only the K concentration of the litter was increased (Table 3). The nutrient content of cassava litter varied substantially over the years and fertilizer treatments, ranging from 34 to

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90 kg N ha^{-1}, 1.9 to 5.0 kg P ha^{-1} and 8.4 to 29 kg K ha^{-1} for two fertilizer levels and three years.

DISCUSSION

Quantities of cassava leaf litter and nutrient contents

The annual trend in cassava litter production was relatively constant but was modified by rainfall (Figure 1). A first maximum is reached in the early dry season. This occurred in December in the second and third years, but high levels were observed in October, November and December in the first year (with substantially higher rainfall). The second maximum appeared in the first months of the subsequent rainy season (May). In the second year (2000–2001), high leaf litter production was recorded probably because the April/May rainfall was greater than in the other years. The magnitudes of the maxima appear to be positively related to rainfall. The lowest leaf litter production occurred consistently in the late dry season in February to April.

Organic matter and nutrient return in cassava leaf litter are substantial. Dry matter ranged from 1.5 to 4.1 t ha^{-1} in our study. This was slightly more than the 0.7 to 3.0 t ha^{-1} observed by Pellet and El-Sharkawy (1997) in Colombia over ten months of growth and the 2 to 2.5 t ha^{-1} recorded by Noordwijk and Purnomisid (1992) in Indonesia over nine months. Part of the cause for higher cumulative totals in our study is that the measurement was done over a longer period of crop growth (harvest at 11 or 12 months). In addition, the measurement in Colombia was made only once at root harvest, so some losses may have occurred.

The amount of litter produced over the growing period can be increased by fertilizer application. We found that although monthly litter production was rarely significantly increased by fertilizer in 1999–2000, cumulative litter production was increased (Table 2). In subsequent seasons, leaf litter production responded to fertilizer application almost every month. Pellet and El-Sharkawy (1997) also observed a positive effect of fertilizer application on litter production at harvest for the four varieties grown, with a range of 0.7 to 1.5 t ha^{-1} for unamended plots and 1.5 to 3.0 t ha^{-1} when 100 kg ha^{-1} each of N, P, and K were applied.

Pellet and El-Sharkawy (1997) observed litter collected at harvest to contain approximately 30 kg N, 2 kg P and 5 kg K ha^{-1}. Our nutrient values were higher, possibly because of differences in methods used. It is probable that our monthly collection of litter reduced losses of nutrients compared to collection of litter from the soil surface at the time of harvesting cassava roots. Potassium is known to be easily leached from vegetation (Norgrove *et al.*, 2000) and N may have been lost by volatilisation or by partial decomposition of the litter in contact with soil particles, a mechanism that is avoided by the use of litter traps.

Transfer functions to estimate leaf litter

Direct estimations of cassava litter production are either labour-intensive or resource-intensive. The leaves must be collected and weighed. A method of estimation of litter fall by counting leaf scars is not adequate. Weight per leaf changes dramatically

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during the year (Figure 2). Van Noordwijk and Purnomisid (1992) took this into account by harvesting, drying and weighing yellow leaves every two to three days, assuming that they would soon fall off. This required frequent visits to the field, which might not be possible if trials are conducted on widely dispersed sites. The litter trap method would allow less frequent visits to the field plots.

Using litter traps we found that the minimum litter DM as a fraction of root DM was 40 %. By contrast, Pellet and El-Sharkawy (1997) found leaf litter in several varieties, fertilizer regimes, and cropping seasons to be approximately 15 % of root dry matter. However, they only collected litter found at harvest and therefore the total amount may have been underestimated. It is also possible that some litter was lost during the 10 month cassava growing period. In our study, litter traps prevented loss of fallen leaves by wind. They also kept the leaves away from contact with the soil and therefore prevented decomposition.

The amount of litter as a fraction of total above ground dry matter was much higher than Kühne (1993) recorded. In our study, the average ratio was approximately 61 % in 2000, 57 % in 2001 and 84 % in 2002 (Table 2) while Kühne (1993) found a ratio of 37 %. Kühne (1993) used a different cassava variety (TMS 30572), which is spreading, with three sympodial branches (INRAB, 1995). So this clone might put more dry matter in stems, which could reduce the ratio of litter to above ground dry matter. But it is more likely that the lower value reported by Kühne (1993) could be due to the fact that he collected leaf litter only during the dry season. Our data (Figure 1) suggest that a substantial proportion of leaf fall occurs at the end of the rainy season and at the beginning of the subsequent rainy season. In our study, the ratio was very much affected by the cropping year. A very dry year (2001–2002) had the highest ratio of litter to total aboveground DM.

Estimation of cumulative litter DM might be possible by relying on relationships with other yield components. Several ratios were calculated between accumulated litter DM and the rest of the cassava crop. The most consistent relationship, based on the relative range of the ratios (range divided by lowest value) over three years, was observed between litter DM and total DM (roots/stems/leaves) as shown in Table 2. The other ratios gave relative ranges of approximately 40 %. However, care must be exercised in using the ratios that were derived from yearly averages. Use of such ratios assumes that the relationship passes through the origin. However, the relationships between litter DM and cassava yield parameters, of which Figure 3 is an example, have intercepts that are statistically different from zero. Thus, at low root yield, there is still substantial litter DM and the ratio between litter DM and its predictor would increase dramatically at very low cassava yields.

As a guide to researchers wanting to estimate litter DM accumulation from studies already conducted, the relationship with fresh root or root DM yield would be most helpful. Confronted with a model consisting of a common slope and three very different intercepts, the question of which intercept to use must be examined carefully. We found that the intercepts were highly correlated to annual rainfall. However, the decrease in litter production during the trial period could be due to nutrient depletion or decreasing rainfall, which were confounded. With this in mind, the user of the

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function could first determine the level of stress to the cassava crop (based on annual rainfall and modified by soil fertility) and use this to determine an intercept to use. Having chosen a value, there would be an error in the relationship with litter DM. The standard error of the predicted litter DM for moderate levels of fresh root yield (15 and 25 t ha^{-1}) was approximately 600 kg ha^{-1}. Therefore a user of the model would have to be willing to accept errors approaching 25 % (0.6 divided by typical litter DM of 2.4 t). The deviation between predicted and observed values of litter DM using the model was approximately 17 % of the predicted value. There would also be error in the measurement of root yield and this would have to be determined from the report and used to increase the corresponding error in the litter DM. Finally, it should be kept in mind that the ratio may not be constant for all varieties.

CONCLUSION

Our study drew on results from several farmers' fields to confirm that cassava produced large quantities of leaf litter ranging from 1.5 to 4.1 t ha^{-1}. Thus, the amount of cassava litter is important information for organic matter dynamics because the quantities are substantial. The amount of nutrients contained in the litter was also not negligible. Fertilizer application increased litter production and the nutrient contents of leaf litter.

Models of soil organic carbon stocks take surface and root litter into account but this critical information is often not available. Estimation of leaf litter in cassava is very useful but rarely done. We have shown that a good estimate of total litter DM can be made from the total dry matter (25 to 29 %) when fresh root yield ranges from approximately 15 to 25 t ha^{-1}. However, we have only shown this for one cassava line. Cassava is known to vary substantially in height of branching, the number of branches, leafiness, and leaf retention. The ratios observed may not be the same for erect non-branching varieties or for excessively branching varieties.

A rough estimate of litter DM can be made also from the root dry matter or even the root fresh weight. Estimations based on fresh root yield would be the most practical for estimating litter DM production from existing reports and it explained 63 % of the variation. Use of the model would require a choice of the intercept to use based on annual rainfall. For those desiring accurate estimates of cassava litter production on dispersed farmers' fields, litter traps are recommended.

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