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Ground cover by three crops cultivated on marginal lands in southwestern Nigeria and implications for soil erosion

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Abstract

Resource-poor farmers in developing nations cultivate marginal lands, thereby exacerbating the problem of soil degradation through poor plant growth and ground coverage. An assessment of ground cover under such a practice will provide a guideline for soil conservation. Ground cover by leguminous cover crops (e.g., *Mucuna pruriens, Pueraria phaseoloides* and *Vigna unguiculata*), associated with yam, maize and rice was measured in three different experiments in southwestern Nigeria using beaded-string method while leaf area was measured using a flat-bed scanner. The leaf area was used in obtaining equivalent of ground cover fraction from the leaf area index. Ground cover by yam was < 15% at 10 wap (weeks after planting) in the second year of cropping and was < 25% at 25 wap in the fourth year of cropping. Maize+legume ground cover was < 40% at harvest (14 wap) in the third year of cropping. At 10 wap, rice 'WAB 189' had significantly higher ground coverage (43.8%) than 'ITA 321' (32.5%) and 'WAB 450' (33.2%). Both the beaded-string and scanning methods were close in the values of ground cover fractions for upland rice, but not for maize, indicating that prediction equation cannot be generalized for crops with different morphology. Cover cropping and residue mulching are good practices for low-intensity cultivation of marginal lands to achieve soil conservation effectiveness.

Additional key words: cover cropping, crop rotation, *Dioscorea* spp, *Oryza sativa*, residue management, soil conservation, *Zea mays*.

Resumen

Recubrimiento del suelo con tres cultivos en tierras marginales del sudoeste de Nigeria e implicaciones en la erosión

Los agricultores con pobres recursos de las naciones en vías de desarrollo cultivan tierras marginales, aumentando el problema de la degradación del suelo debido a un escaso crecimiento de las plantas y pobre cobertura del suelo. Evaluar la cobertura del suelo bajo estas prácticas aportará información para la conservación del suelo. En tres experimentos diferentes en el sudoeste de Nigeria se ha medido la cobertura del suelo en cultivos asociados de leguminosas (*Mucuna pruriens, Pueraria phaseoloides* y *Vigna unguiculata*) con maíz, ñame, y arroz, usando el método de la cuerda marcada y un medidor de área foliar. Se obtuvo la fracción de cubierta del suelo a partir del índice de área foliar. La cobertura del suelo por el ñame fue < 15% 10 sdp (semanas después de la plantación) en el 2º año de cultivo, y < 25% a las 25 sdp en el 4º año del cultivo. La cobertura del suelo con la asociación de maíz y leguminosas fue < 40% en el momento de la cosecha (14 sdp) en el 3er año del cultivo. El arroz 'WAB 189' cubrió el 43,8% a los 10 sdp, considerablemente más que 'ITA 321' (32,5%) y 'WAB 450' (33,2%). La cuerda marcada dio valores de la cubierta del suelo próximos a los del medidor de área foliar en el caso del arroz de las tierras altas, pero no en el maíz, indicando que la ecuación de predicción no puede generalizarse para diferentes cultivos. La cobertura de cultivos y el acolchado con residuos vegetales son prácticas convenientes para una eficaz conservación del suelo en las tierras marginales.

Palabras clave adicionales: conservación de suelo, cultivo cobertura, *Dioscorea* spp, manejo de residuos vegetales, *Oryza sativa,* rotación de cultivos, *Zea mays.*

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Introduction

A basic soil conservation requirement is that the soil should be adequately covered either by vegetation or a synthetic (and or organic) material to prevent soil erosion. This requirement is not often met on disturbed landscapes where natural vegetation has been removed. On cultivated lands, this is usually so when crops have not developed extensive canopy at early growth stages and conservation tillage practices or cover cropping are not adopted. In most of the developing nations of the world, most areas that have been previously eroded and degraded due to non-adoption of these conservation practices, in the first instance, are returned to cultivation without adequate fallow. Variability in soil productivity is accentuated with soil degradation on sloping lands (Salako *et al*., 2007). According to these authors, the upper slope of a gravelly Alfisol in southwestern Nigeria was more resistant to soil degradation as 16-67% loss in maize yield was observed compared to 65-75% loss in yield at the lower slope. Efforts have been geared toward rehabilitating such marginal lands or sustaining their productivity with low-input technologies suitable for adoption by the resource-poor farmers of these nations (Kang *et al*., 1997; Kirchhof and Salako, 2000; Zhang *et al*., 2004; Salako *et al*., 2007).

Cropping systems that adopt cover cropping can provide up to 100% ground cover, for instance, with *Mucuna pruriens* (Anthofer and Kroschel, 2005). However, when crops are grown as monocrops, the early growth stages do no provide ground coverage and depending on the crop, this can persist for several weeks. For instance, a crop like yam (*Dioscorea* spp.) takes several weeks of the early growth stages to provide reasonable ground coverage (Onwueme, 1978). Runoff and soil erosion are strongly and positively or negatively correlated with ground cover (El-Swaify *et al*., 1988; Renard *et al*., 1997; Frasier and Hart, 2003; Gabriels *et al*., 2003; Zhang *et al*., 2004). Therefore, the conservation effectiveness of any crop rotation systems depends on ground coverage effectiveness of the individual crops in the system (Gabriels *et al*., 2003; Jankauskas and Jankauskiene, 2003) and residue management (Fischer *et al*., 2002).

In view of the importance of ground cover in soil and biodiversity conservation, there have been concerted efforts geared toward rapid and accurate assessments. The methods range from simple visual or beaded-string technique (Sarrantonio, 1991) to the use of remote sensing techniques (Biard and Baret, 1997; Daughtry *et al*., 2004). When ground coverage of crops on marginal lands is assessed, it provides insight into processes of soil degradation and how to manage such lands with the adoption of appropriate cropping intensities and soil conservation practices, where their utilization is inevitable. Furthermore, it is a maxim in soil conservation that when the ground is adequately covered, soil erosion is prevented. This is not often achieved at the early stages of crop growth if complementary practices such as mulching are not adopted. Assessing ground coverage of crops in relation to current trends (e.g., reduction in fallow period) in land use by traditional farmers will help in land-use planning. Also, a comparison of simple methods of assessing ground coverage with more sophisticated methods is necessary to determine the applicability of methods of ground coverage measurement, particularly, because resource-poor farmers can be educated to practically adopt such simple methods for soil conservation planning if they prove effective. Therefore, this study was carried out in southwestern Nigeria with the aim of (i) assessing fraction of ground cover in a maize-yam rotation on a previously eroded land managed with herbaceous legumes, (ii) assessing the fractions of ground coverage by rice and maize grown with low-input technologies on a physically degraded and eroded site, and (iii) determining the relationship between the simple beaded-string method and a flatbed scanning technique in the assessment of ground cover.

Material and Methods

The experiments were designed to investigate effectiveness of ground cover by common crops during the rainy season, using traditional farming (e.g., mounding with hoe, no or low-input technologies) and recommended conservation practices (e.g., mulching) after a short fallow period of < 6-yr. Short-fallowing is now a common practice in many tropical regions. So, the experiments have been designed to understand the possible predisposition of such poorly rehabilitated soils to further soil degradation due to poor establishment of crops.

The studies were carried out in the same agro-ecological zone but at two locations, Ibadan (latitude 7° 30' N and longitude 3° 54' E) and Abeokuta (latitude 7° 9' N and longitude 3° 21' E), southwestern Nigeria, with similar gravelly soils; however, the studies were conducted in different years. Representative soil characteristics were reported by Kirchhof and Salako

(2000). The surface soil (0-20 cm) at both locations had particle size distribution of 74-84% sand, 14-17% silt and 2-10% clay (generally loamy sand). Surface soil pH (1:1 $H_2 0$) ranged from 5.6-6.7; organic C from 1.2-3.2%; Bray-1 P from 2-2.24 mg kg^{-1}. Gravel concentration ranged from 4.0-16.5% depending on the intensity of soil erosion.

There were three experiments carried out at the two locations:

At Ibadan, Experiment 1 was located at the International Institute of Tropical Agriculture (IITA) and was conducted between 1996 and 1999. In this report, only data covering 1997-1999 are presented as Kirchhof and Salako (2000) had earlier reported the 1996 data. Long-term mean annual rainfall for Ibadan is 1,300 mm. The site was previously used for soil erosion studies and was left from 1992-1996 to natural fallow. The soil is a gravelly Oxic Kandiustalf (Moormann *et al*., 1975; FDALR, 1990) and fallow vegetation at the site was 31 Mg ha^{-1}. Each plot size was 4 m wide × 20 m long on an 8% slope.

Experiments 2 and 3 were carried out at the University of Agriculture, Abeokuta in 2001 on a previously cultivated watershed that was physically degraded. Long-term average of annual rainfall is 1,200 mm. Like Ibadan, the vegetation is a forest-savanna transition on a gravelly Oxic Kandiustalf.

Experiment 2 was set up on eroded sites where subsoil gravel were exposed in various degrees indicating differences in severity of past erosion. In 2001, the fallow vegetation (about 4-yr old) at the location comprised grass and herbaceous species biomass of 18 Mg ha^{-1} and woody biomass of 32 Mg ha^{-1}.

Experiment 3 was located at an upper slope position to Experiment 2. This was a field cultivated by farmers in the previous 3 years. Thus, two contiguous farms under mechanical and manual (mound) tillage were selected to lay out the third experiment.

The three experiments were conducted at two locations that were marginal lands in view of (i) previous soil degradation by soil erosion and (ii) inadequate or zero fallow period when compared to more that 10-year fallow period in traditional shifting cultivation practices.

Experimental designs

Experiment 1: Maize-yam rotation with herbaceous legume and residue management

The natural fallow vegetation was cleared manually in 1996. There were 12 runoff plots in which legumes and residue management (burned or used as mulch), as treatments, were replicated twice. Thus, a factorial experiment was set up in which the two factors studied were legumes and residue management. The legumes were *Vigna unguiculata* (L.) Walp (cowpea, cv. IT84X-2264), *Mucuna pruriens* (L.) DC (cv. *Utilis*) and *Pueraria phaseoloides* (Roxb.) Benth; an edible legume (cowpea) versus two non-edible legumes. The legumes were grown as intercrops of maize (*Zea mays* L. cv. TZESR-SRW) in 1996 and 1998. Their residues were either burned or used as mulch for subsequent cultivation of yam (*Dioscorea* spp., cv. TDR 131) in 1997 and 1999. In 1996, maize + legume was cultivated on the flat (Kirchhof and Salako, 2000) whereas from 1997-1999, cultivation was on mounds to accommodate traditional practice of yam cultivation. Mound height was about 25 cm and its base was 1 m in diameter. There were 80 mounds per plot. For maize+legume, cowpea and *P. phaseoloides* were planted at the same time with maize whereas *M. pruriens* was planted two weeks after planting (wap) maize to eliminate the potential ability of covering maize by its rapid growth. The legumes were planted in furrows across the slope at 0.25 m intra-row spacing. Maize seeds were planted round the base of mounds in four holes per mound to obtain a population of 40,000 plants ha^{-1}. One yam sett had an average weight of 269 g and yam was not staked allowing the biomass to cover the ground during growth. All field operations were carried out manually.

Experiment 2: Cultivation of upland rice varieties with poultry manure and NPK

The plots (n = 96) were laid out in 3 replicates at random across slope with each plot size being 3 × 4 m. There were 48 plots each in two contiguous segments of the land that were classified as fairly and severely eroded segments by visual assessment of gravel exposure on the surface. Minimum tillage was carried out with hand hoe. The factors in this experiment were nutrient amendment and upland rice cultivar. Thus the treatments or levels for nutrient amendments were (i) no amendment; (ii) full NPK (15: 15: 15), in 2001 was applied at the rate of 200 kg ha^{-1}; at planting by broadcasting; (iii) full poultry manure, applied at 15 Mg ha^{-1} three weeks before planting and worked into surface soil with hoe; and (iv) $^1/_2$ poultry manure + $^1/_2$ NPK.

Rice (*Oryza sativa* L.) cultivars used were ITA 150, ITA 321, WAB 189-B-B-B-8-HB (designated WAB 189) and WAB 450 1-B-P38-HB (designated WAB 450). Field operations were carried out manually

Experiment 3: Cultivation of maize with flat and mound hoe tillage

Two contiguous farmers' fields which were cultivated in the previous 3 yr were chosen. One was under mechanical (conventional) tillage and the other was under manual (mound) tillage. Both fields were previously cropped to maize on a slope of 5% and had been eroded. A split-plot experiment in a randomized complete block was imposed with four replications. Each plot size was 4×5 m.

The main plots were tillage methods; flat tillage on the mechanically cultivated site and mound tillage on the manually cultivated site. Flat tillage was carried out with hoe by making flat seedbeds up to 15 cm depth whereas mound tillage was achieved by breaking down and rebuilding existing mounds to a height of about 25 cm and 1 m base diameter. Flat tillage was particularly necessary on the mechanically tilled soil because the soil was compacted, apart from being eroded.

The sub-plots were soil nutrient management methods: *M. pruriens* (cv. utilis) planted at 2 wap maize, poultry manure was applied at 15 Mg ha^{-1} at 3 weeks before planting maize and no soil fertility management served as control. The NPK concentrations of poultry manure were 27:113:35 g kg^{-1}. Maize was seeded in April 2001 (cv. Acr 97 T2L Com.1-W) at a spacing of 0.25 m within row and 1 m between rows. *M. pruriens* was planted in the inter-rows at 0.25 m spacing within rows. Maize was seeded round the mound base to obtain the same population of plants as in flat tillage plots, whereas *M. pruriens* was planted in the furrows.

Measurement of ground cover and leaf area

Ground cover (%) was evaluated using the beaded-string method (Sarrantonio, 1991) in all experiments and the DELTA-T (trademark) scanner (Kirchhof and Pendar, 1993) in Experiments 2 and 3. The beaded-string method comprised marking a white string at 15 cm interval and counting only the number of marks corresponding to surfaces of leaves along the diagonal of a plot segment, relative to the total marks on the string. Two diagonal measurements were taken and the average counts calculated. Ground cover was the ratio of counted marks to total marks. Measurements of ground cover were carried out at various stages of growth for the different crops in the experiments.

For the scanning method, two leaves (one large and one small) were cut at the stalk base from 5 stands per plot and taken to the laboratory for scanning for both rice and maize. The leaves were scanned at a scanner resolution of 300 dpi and the images were analyzed using the area option of the DELTA-T scanner software. Thus, mean leaf area for a single leaf was obtained. This was used to calculate total leaf area per land area (leaf area index) using the number of leaves in the area. Leaf number per stand for 10 stands was counted to calculate number of leaves per area. Above-ground biomass of crops was harvested for drying at 60°C to constant weight and weighed for dry matter yield per hectare. Plant heights were also measured at different growth stages.

Data analysis

Analyses of data were carried out using SPSS for Windows (SPSS, 1999). Analysis of variance was done to separate means for the various treatments. Least significant (LSD) differences were reported at $P \leq 0.05$. Regression equations (Chatterjee and Price, 1991) were developed with different regression models (linear, logarithmic, power and exponential) to obtain best-fit equations relating the parameters measured, using coefficients of determination, r^2 and probability level of significance.

Results

Ground cover by crops in rotation as affected by legumes and residue management

Maximum ground cover by yam was 68% under *M. pruriens* in 1997, after which ground cover decreased due to senescence of leaves (Fig. 1). Significant differences for the effects of the legumes on ground cover were observed at 10, 13, 20, 23 and 26 wap whereas there were no differences at 16 and 32 wap. Effects of residue management were also significant at the same time as effects of legume, except at 26 wap when residue management had no significant effect on ground cover. The tendency toward an increase in ground cover at 32 wap was due to unstable position of senescence leaves under wind influence. Yam on *M. pruriens* plot had

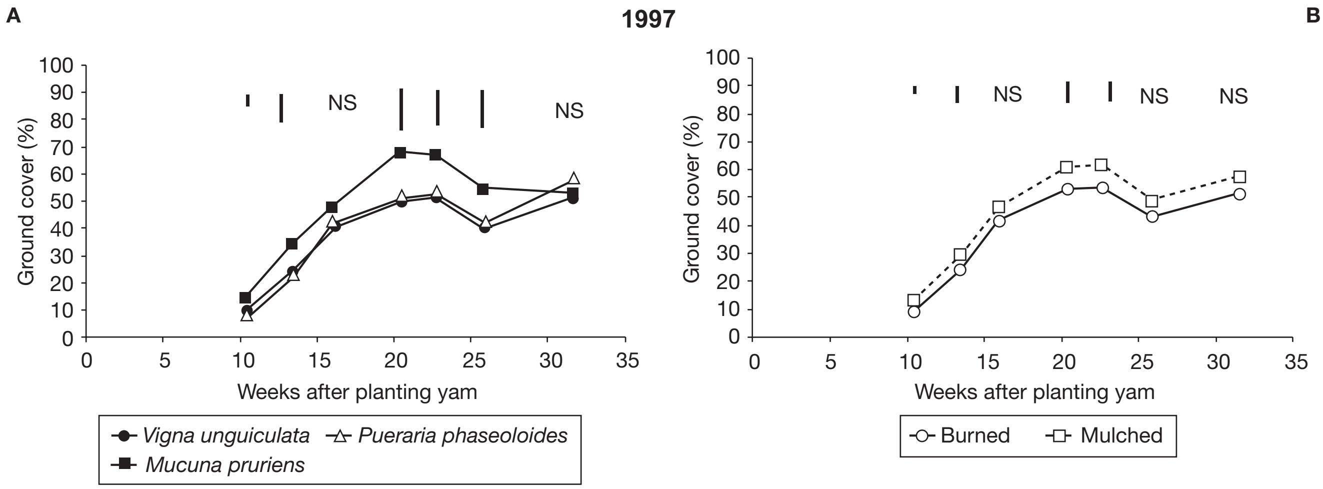

Figure 1. Ground cover as affected by (A) legume and (B) residue management under yam cultivation in 1997. Vertical bars show least significant differences.

higher ground cover than yam on *P. phaseoloides* and cowpea plots. Also, ground cover was better with yam under mulched-residue than burned- residue. Ground cover by yam was less than 15% at 10 wap.

In 1998, ground cover by maize + legume exceeded 15% with maize + cowpea and maize + *M. pruriens* at 6 wap maize (Fig. 2). At 8 wap, cowpea and *M. pruriens* plots had higher ground cover than *P. phaseoloides* plot. This was a period of full maturity for cowpea. However, by 14 wap (maize harvest period), only cowpea plot had higher ground cover than the *P. phaseoloides* plot, and this difference was maintained till 16 wap maize or 2 weeks after harvesting maize. Under the maize + legume growth period, maximum ground cover was between 20 and 32%. After this period, drying of leaves of maize caused reduction in ground cover but provided a boost for vigorous growth of legumes and natural fallow. Thus, ground cover of about 100% was achieved before 20 wap maize. There was virtually no significant difference due to residue management (Fig. 2).

Yam growth was poorer in 1999 with the ground cover less than 20% even at 25 wap (Fig. 3). At 10 wap, ground cover was less than 3%. The highest ground cover up to 20 wap yam was provided by yam on *P. phaseoloides* plot, and these cover percentages were significantly higher than the cover by yam on *M. pruriens* plot. At 25 wap, *M. pruriens* plot yam had a lower cover than cowpea plot yam. Also in this year, residue management barely had a significant effect on yam ground cover (Fig. 3).

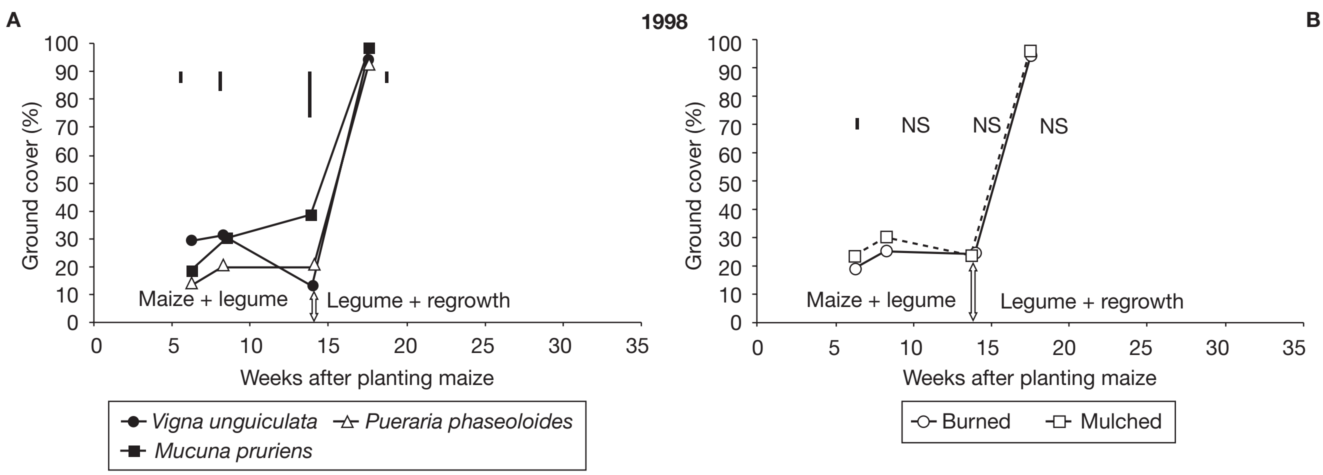

Figure 2. Ground cover as affected by (A) legume and (B) residue management under maize + legume cultivation in 1998. Vertical double arrow indicates ground cover at the time of maize harvest, after which only legume + regrowth were left.

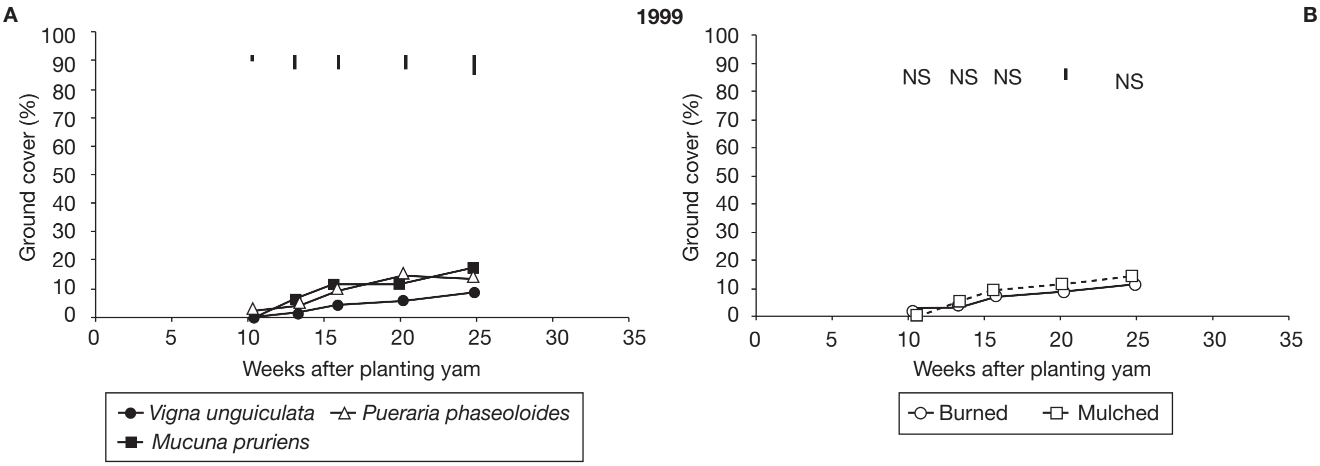

Figure 3. Ground cover as affected by (A) legume and (B) residue management under yam cultivation in 1999.

Ground cover by rice in relation to soil amendment and upland rice variety

There were no significant differences in the overall means of ground cover due to soil fertility management. However, differences were observed among rice cultivars (Table 1). Also, there was no significant difference between the ground cover fractions of the beaded-string and scanning methods. By using the scanning method, LAI was estimated.

A highly significant linear relationship ($P < 0.0001$) was found between ground cover (fraction) and dry above ground biomass (kg ha^{-1}) (coefficient of determination, $r^2 = 0.46$, number of observations, n = 141) at 7 and 10 wap. However, the regression points and residuals were poorly distributed, necessitating the transformation of data to logarithmic values before linear regression which resulted in a better distribution and relationship as follows:

$$Y = -1.926 + 0.472X, \quad r^2 = 0.76, \quad P < 0.0001 \quad [1]$$

Table 1. Ground cover fractions obtained by the beaded-string and scanning methods for rice cultivars at 7 and 10 weeks after planting (wap)

Rice variety	Beaded-string method		Scanning method
	7 wap	10 wap	10 wap
ITA 150	0.124	0.382	0.390
ITA 321	0.102	0.325	0.373
WAB 189	0.157	0.438	0.512
WAB 450	0.940	0.332	0.358
LSD ($P \leq 0.05$)	0.055	0.056	0.123

where Y = logarithmic values of ground cover (fraction) by beaded-string method and X = logarithmic values of dry above ground biomass (kg ha^{-1}).

Apart from the improvement of a very high r^2 and significant relationship with logarithmic transformation, the standardized residuals were well distributed between 2 and –2.

A linear regression between the two methods at 10 wap rice was developed:

$$Y = 0.243 + 0.328X, \quad r^2 = 0.44, \quad n = 72, \quad P < 0.0001 \quad [2]$$

where Y = ground cover fraction by beaded string method and X = ground cover fraction by scanning (LAI).

The linear relationship between ground cover fraction (Y) by beaded-string method and leaf area of a single leaf, X (cm^2) is:

$$Y = 0.197 + 0.0122X, \quad r^2 = 0.40, \quad n = 72, \quad P < 0.0001 \quad [3]$$

Leaf area of rice measured by scanning was significantly ($P < 0.003$) related above-ground biomass but r^2 was low (r^2 between 0.13 and 0.16 for various models). Also, leaf area was not related to leaf number. A single leaf area at 10 wap for ITA 150 was 14 cm^2; 13 cm^2 for ITA 321, 17 cm^2 for WAB 189 and 14 cm^2 for WAB 450 [LSD ($P < 0.02$) = 3.46].

Leaf area of maize and ground cover as influenced by tillage and soil fertility management

A single leaf area of maize ranged from 254-315 cm^2 without significant differences for tillage and soil organic amendments at 6 wap maize. Furthermore, the area of a single leaf did not correlate with ground cover fraction measured. However, significant relationships ($P < 0.0075$) were found for these data between single leaf area and leaf number on each maize stem; r^2 was 0.19 for the linear model, 0.21 for the logarithmic model and 0.30 for the power law model. The relationship with a power law model is:

$$Y = 3.1186X^{1.7698} \quad r^2 = 0.30, \quad n = 40, \quad P < 0.001 \qquad [4]$$

where Y = the area of one leaf (cm^2) and X = leaf number per stem of maize.

The total leaf area per stem was not significantly affected by treatments and it ranged from 3,120-3,937 cm^2. Leaf area (6 wap) eventually influenced maize yield at 14 wap as shown by the following linear relationship:

$$Y = 207.8+27.16X, \quad r^2 = 0.31, \quad n = 21, \quad P = 0.006 \qquad [5]$$

where Y = leaf area of a single leaf (cm^2) at 6 wap and X = fresh cob yield (Mg ha^{-1}) at 14 wap.

Maize height at 6 wap was 59.7 cm for flat tillage and 45.1 cm for mound tillage with a significant difference at $P = 0.002$. Soil fertility treatment had no significant effect on maize height.

Ground cover fraction was significantly influenced by tillage and soil nutrient management practices but not by the interactions of the two treatments (Table 2). There was a more effective coverage by maize cultivated with flat tillage than maize cultivated with mounds. Also, *M. pruriens* significantly influenced ground coverage by maize but poultry manure did not.

Table 2. Ground cover fraction by maize as influenced by tillage and soil nutrient management practices on a marginal land in Abeokuta, southwestern Nigeria

Tillage	Soil nutrient management			Mean
	Mucuna pruriens	Poultry manure	None	
Flat	0.116	0.104	0.085	0.102
Mound	0.095	0.064	0.049	0.0691
Mean	0.105	0.084	0.067	
LSD ($P \leq 0.05$)				
Tillage (T)				0.033
Soil nutrient management (SNM)				0.038
(T) × (SNM)				NS[1]

[1] No significant difference.

Discussion

The various experiments reported in this study were carried out on marginal lands because the soils were physically degraded and fallow periods were either zero or less than 6-yr. Kang *et al*. (1997) and Salako and Tian (2003) suggested that a longer fallow period than 4 or 6-yr would restore soil productivity of physically degraded Alfisols in Ibadan, southwestern Nigeria, particularly when the soil was tilled. A major reason for this was that at 7-8-yr of fallow, litter production for organic matter build-up was high, ranging between 10 and 14 Mg ha^{-1} yr^{-1}, with natural fallow having the highest rate (Salako and Tian, 2001).

Cultivation of these marginal lands resulted in poor ground coverage by the three crops studied (Figs. 1-3; Tables 1 and 2). The maize-yam rotation system was not an effective soil conservation crop management practice, except with cover cropping and residue mulching. Even at that, the cropping intensity on the previously eroded site should be limited to 2-yr of cropping after the short fallow period to allow for another fallow. The data suggest that severe soil degradation caused by soil erosion in this region can be linked to land use intensification, which has a consequence of poor vegetal growth even with nutrient amendments if the basic cause of degradation was physical. Gabriels *et al*. (2003) reported that it is not all crop rotation systems that reduce soil erosion and the crop management factor, C, in the Universal Soil Loss Equation (Renard *et al*., 1997) tends to be high with rotations where maize was frequently used.

Leaf area is influenced by factors such as age, plant type and population density. Nonetheless, it can be deduced that the leaf areas and leaf area indices (LAI) in this study were very low, indicating poor growth. For instance, at maturity, Kiniry *et al*. (2001) reported LAI as high as 12.7 for rice while Stewart *et al*. (2003) reported LAI as high as 4.7 for maize. Elings (2000) reported an average leaf area of 686 cm^2 for maize cultivated in Mexico at flowering. The need for low cropping intensity was reflected in very poor ground cover by yam in the fourth year of the crop rotation system (Fig. 3). The rice variety cultivated was important in adaptation to the degraded site (Table 1) just as tillage was necessary to enhance crop growth (Table 2).

A very good prediction of above-ground biomass of upland rice can be obtained from ground cover fraction with the simple beaded-string method (Eq. [1]). However, ground cover fraction by this method cannot be used for all crops as an estimate of LAI, as indicated by the agreement between the beaded-string and scanning methods (Eqs. [2] and [3]) for rice and lack of such an agreement for maize. Furthermore, while leaf number and leaf area had no relationship for rice, they were significantly related for maize (Eq. [4]). This is attributed to differences in plant growth characteristics and spacing. Attempts at estimating crop LAI from ground coverage using remote sensing techniques have also met with limited success (Duchemin *et al*., 2006). Leaf area was significantly related to fresh maize cob yield (Eq. [5]). Thus, it can be inferred from Eqs. [1] and [5] that crop yields could be predicted from leaf area, but better in rice than maize. The low-intensity cultivation recommended in this study can be based on the recommendations of Salako (2003), in which 1-yr of cropping is to be followed by 2 or 3-yr of fallow (25-33% cropping intensities).

In conclusion, adequate ground coverage by crops grown on previously degraded soils after short or no fallow periods was very difficult to obtain, except by adopting cover cropping and residue mulching in soil management. For instance, yam coverage of ground was less than 25% at 25 wap while maize + legume provided less than 40% cover at 14 wap by the last years of cropping in the maize-yam rotation that lasted 4-yr. Consequently, cultivation of such lands could lead to a more severe degradation if appropriate soil conservation measures are not adopted. Ground coverage by rice depended on the variety grown, suggesting that some rice varieties could grow well, vegetatively, on marginal lands. However, this choice of varieties for effective soil conservation must be considered along with profitable grain yield. Although the ground coverage measurement with the simple beaded-string method was as good as scanning method for rice, such significant relationships were not observed for maize. Thus, the prediction equations cannot be generalized for crops with different morphology.

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