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Promising practices for sustainable intensified systems in the savannah zone of West Africa

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Abstract — Leguminous rotations and fallows are sustainable and productive soil management practices. This paper will focus on soybean [*Glycine max*] and cowpea [*Vigna unguiculata*] rotation in the mono-modal savanna and Mucuna [*Mucuna pruriens* var. *utilis*] fallow in the bi-modal savanna zone. Although the grain legumes export considerable N in the grain, they are most likely to be adopted in the savanna zone with mono-modal rainfall and can be managed for optimum benefit. Mucuna must generally be limited to the zones where a long growing season allows growth of Mucuna and a food crop. The paper will focus on benefits of the rotations/fallows and draw heavily on recent results. Best practices for all the systems include using the longest possible maturing cultivar, ensuring adequate P nutrition, and following the legume with a non-legume as soon as possible.

Résumé — Des pratiques prometteuses pour la durabilité de systèmes intensifs en zone de savanes d'Afrique de l'Ouest. Les rotations avec des légumineuses et la jachère sont des pratiques de gestion des sols durables et productives. Ce texte analyse les rotations à soja [*Glycine max*] et niébé [*Vigna unguiculata*] dans les savanes à pluviométrie monomodale, et les jachères à [*Mucuna pruriens* var. *utilis*] dans les savanes à pluviométrie bimodale. Bien que les légumineuses exportent beaucoup de N dans leurs graines, elles sont plus appropriables par les producteurs et leurs effets peuvent être mieux gérés. Le domaine de recommandation de la jachère plantée en Mucuna est limité aux zones où une longue saison des pluies permet de cultiver le mucuna et une culture vivrière à la suite au cours de la même saison. Ce texte s'intéresse en particulier à l'intérêt des rotations et des jachères, en mettant l'accent sur les résultats les plus récents. Parmi les meilleures pratiques pour les différents systèmes, il faut noter l'utilisation de cultivars à long cycle de maturation, une nutrition suffisante en P, et une succession la plus rapide possible entre la légumineuse et la céréale qui la suit.

Introduction

Leguminous rotations and fallows are the key to sustainable and productive soil management. They require less N for growth and produce a high protein product. Use of legumes replaces a small part of the N fertilizer required by subsequent cereals in a rotation. The major areas of emphasis of IITA in the savanna zone over the last 7 years have been on grain legume rotations and cover crop fallows. Grain legumes are more likely than herbaceous legumes to be adopted by farmers but their potential contribution may be low because of export of nutrients in the grain. Taking this into account we have tried to optimize the benefits of the grain legumes, especially soybean and cowpea, while studying the adoptability of the cover crop systems. This synthesis paper focuses on soybean and cowpea systems in the mono-modal rainfall zone and Mucuna fallows in the bi-modal and long mono-modal rainfall zones, although we also work on other grain and herbaceous legumes in other agro-ecological zones.

Benefits from best legume systems

Soybean rotation

Agronomic work conducted in the Guinea savannah zones of West Africa has shown that the yield of maize improves in a rotation system with soybean (Sanginga *et al.*, 2001). Published estimates of N fertilizer replacement values (NFRV) from soybean in the mono-modal savanna zone of West Africa range from 20 kg N/ha (Carsky *et al.*, 1997) to 45 kg N/ha (Kaleem, 1993). These estimates appear to be high in comparison with recently completed work in several sites in northern and central Nigeria with several soybean lines. Ogoke *et al.* (2001) reported NFRV of 0 to 17 kg/ha and Singh *et al.*, (2001) found mean values of approximately 5, 10, and 20 kg/ha when soybean residues were exported, surface-applied, and incorporated, respectively (Figure 1). Furthermore, NFRV reflects not only the direct effect of N fixation but also the N sparing effect. Also there are non-N benefits of soybean rotation. For example, Carsky *et al.* (2000) reported reduced *Striga hermonthica* parasitism on maize after soybean compared with a sorghum control.

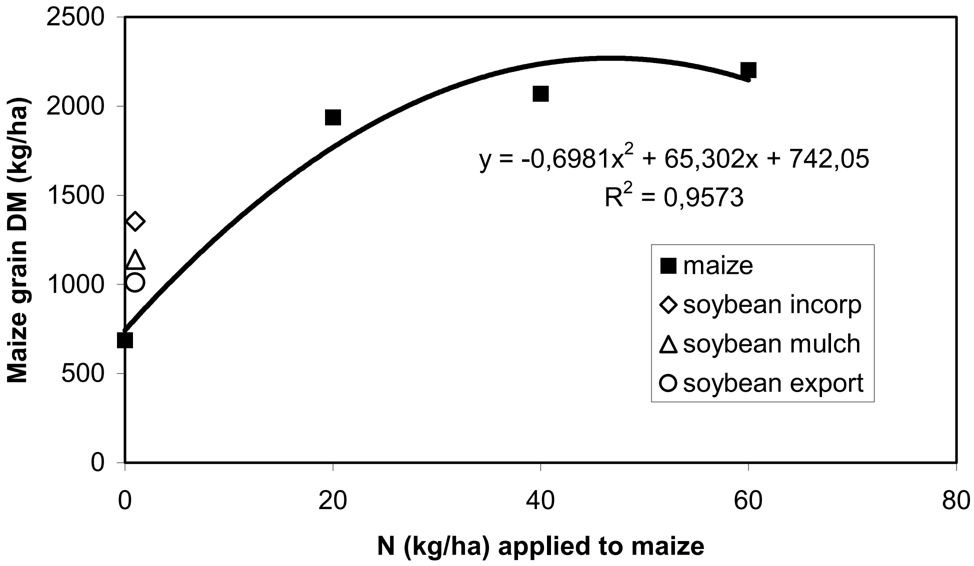

Figure 1. Effect of management of soybean residues on soybean rotation effect (Singh *et al.*, 2001).

An estimate of the direct contribution of soybean to maize was obtained by Sanginga *et al.* (2001) by the indirect ^{15}N labeling method. Residual N values between 10 and 24 kg/ha were obtained in the first maize crop after soybean, representing 14 to 36% of the maize total N, while the total N difference method gave values varying between 16 and 23 kg N/ha (Sanginga *et al.*, 2001). It is clear that the BNF benefit to non-legumes due to the inclusion of legumes in a cropping system is small indeed compared to the level of N needed for high yields (Carsky and Iwuafor, 1999). Promising results are being gathered in the northern Guinea savanna of Nigeria where grain yield of maize grown after soybean and receiving 45 kg N/ha as urea is similar to that of maize grown after maize receiving 90 and 120 kg N/ha (Sanginga *et al.*, 2001). Adoption rates of soybean in the Guinea savannah are high due to new varieties that resist shattering and store well (Sanginga *et al.*, 1999; Sanginga, *et al.*, 2001). IITA also screens their soybean lines for N fixation potential, P-use efficiency, haulm production, and *Striga hermonthica* germination potential (Sanginga *et al.*, 2001).

Cowpea rotation

A synthesis of results from the savanna zone of West Africa suggests that cowpea rotation can be considered to be an effective resource management technology in cereal-based systems (Carsky *et al.*, 2002). Part of the N requirement of cereal crops can be satisfied by cowpea crop rotation. The estimates of N fertilizer replacement value for cowpea range from 10 kg N/ha (Carsky *et al.*, 1999) to 80 kg N/ha (Horst and Hardter, 1994). Higher estimates were observed in conditions where residues were incorporated into the soil (Kaleem, 1993; Dakora *et al.*, 1987) or where two crops of legume were grown in one season (Horst and Hardter, 1994). NFRV was only 9 kg/ha for one season of cowpea in the first year followed by one season of maize in the second year in the Guinea savannah of northern Nigeria at latitude 11° N (Carsky *et al.*, 1999). This suggests that a long dry season reduces the benefit of cowpea. Jeranyama *et al.* (2000) grew cowpea and crotalaria as relay intercrops with maize for two years followed by a maize test crop in the third year and calculated a NFRV of 36 kg/ha. Bagayoko *et al.* (1997) estimated the NFRV to be approximately 40 kg/ha at Cinzana, Mali (latitude 13° N). In that long-term trial the control system was continuous millet and both phases of cowpea millet rotation allowed estimation of the effect for four years. Continuous cereal monoculture is likely to give higher estimates of NFRV than fallow because of higher N export by the cereal and greater soil N depletion.

Rodriguez (1986) reported that maize grain yield after cowpea was higher than maize after maize with 150 kg N/ha. There was little or no residual benefit from intercropped cowpea in this trial, which was conducted for 4 years in Burkina Faso. It should be noted that soil fertility, especially P, was adequate for good cowpea growth, a pre-condition for a good residual effect. As for soybean discussed above, the NFRV is a reflection of direct N contribution plus the N-sparing effect, plus non-N effects. Non-N effects may be estimated by contrasting the benefits of rotation with a monoculture control with a non-monoculture control. The synthesis of Carsky *et al.* (2002) shows that the effect of cowpea rotation is greater when the control system was monoculture cereal (i.e. millet after millet or maize after maize). Yield increase after cowpea compared with monoculture cereal was 80%, but only 31% when the control was not a monoculture. A monoculture control treatment may have more pest and disease problems than a cereal rotation system and the benefit of cowpea in this case (providing a break in pest and disease cycles) could be provided by many non-leguminous crops. The results of Reddy *et al.* (1994) suggested that the positive effect of cowpea rotation appeared to be related to incidence of *Striga hermonthica* on the cereal test crop as there was more *Striga hermonthica* on millet after millet than on millet after cowpea. It is not clear whether cowpea actually reduced *Striga hermonthica* incidence or whether it simply did not result in build-up as the millet did. (Ariga *et al.*, 1994) showed how a preceding crop of cowpea variety TVx 3236 reduced *Striga hermonthica* density on a subsequent maize crop and increased maize yield. The effect increased with the duration of growth of the cowpea crop.

Acceptance of cowpea rotation is bound to be high as cowpea is a highly prized food in West Africa. Dembélé (2000) for example recorded grain legume systems adoption in Mali to be many times higher than adoption of forage legumes. Oyewole *et al.* (2000) found that farmers preferred cowpea-maize to Mucuna-maize double cropping to keep grain producing cowpea in the system although the benefit to maize of cowpea was less than that of Mucuna.

Mucuna fallow system

Planted fallow with Mucuna has been adopted by many farmers in Benin, Honduras, and elsewhere (Manyong *et al.*, 1999; Buckles, 1995). A short Mucuna fallow (less than one year) has been shown to improve the yield of succeeding crops under various situations. In some cases, this was linked to improvement in soil physical and chemical properties. The most common benefit of Mucuna fallow is related to the improved N nutrition of a subsequent cereal crop, which is mostly related to the biomass and N content of the Mucuna fallow (Carsky *et al.*, 2001c). Other benefits such as weed suppression may frequently outweigh soil fertility considerations in the minds of farmers.

While Mucuna may be useful in some situations, the synthesis of Carsky *et al.* (2001c) makes clear that it does not grow well everywhere. Major constraints to Mucuna biomass accumulation are low soil P availability and high soil acidity. Furthermore, multi-season trials indicate that the benefits of Mucuna fallow are not long lasting. Thus the soil fertility benefit alone may not generally justify farmers' investment in a Mucuna cover crop. Mucuna is more likely to be grown during the agronomically marginal second growing season in the bi-modal rainfall zone. Niches in cropping systems in which

Mucuna is likely to be adopted by farmers are limited and can be defined in terms of climate, soil, and infrastructural environment. Prime niches for Mucuna fallow are (1) the dry season in areas with high rainfall or on soils with high water-holding capacity and (2) during "short rainy seasons" in the bimodal rainfall distribution zone. These have been taken into account in developing a map of the adoption domain for Mucuna fallows (figure 2). Extension of our predicted adoption domain toward the mono-modal savannah may occur where Mucuna has secondary benefits such as animal feed, human food, and *Striga hermonthica* reduction.

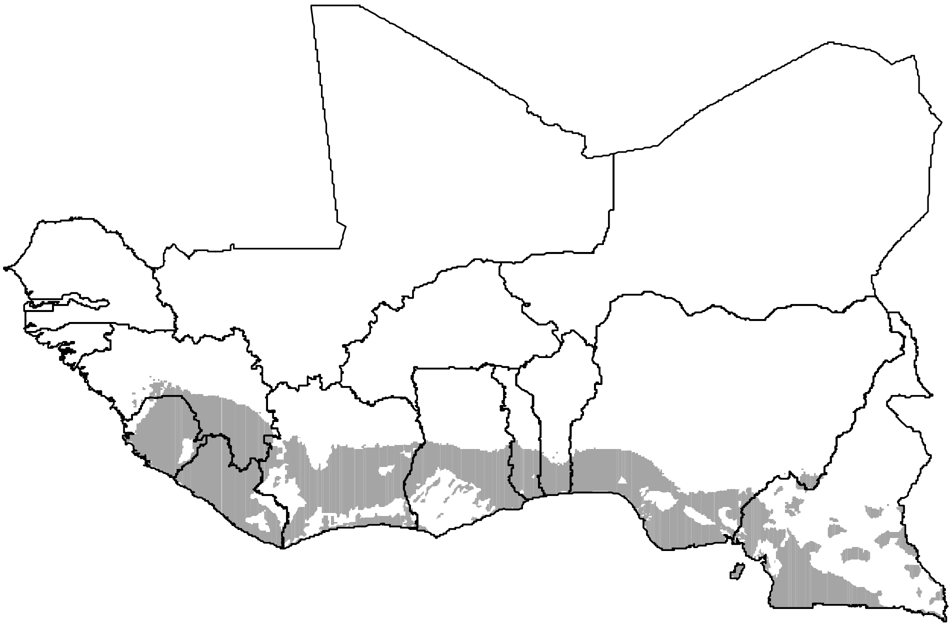

Figure 2. Area in which Mucuna will grow well (coverage of acid soils less than 75%, coverage of P-fixing soils less than 90%, and length of growing period greater than 150 days) and where a mucuna fallow will allow one food or cash crop per year (length of growing season greater than 240 days). From Carsky *et al.* (2001c).

Best practices to guide design of intensified cropping systems

Legume maturity cycle

We have hypothesized that a longer duration soybean crop would provide a better rotational effect as long as the harvest index is not too high. This was observed for two soybean varieties of differing maturity and their contribution to maize (Carsky *et al.*, 1997). This has been confirmed by (Ogoke *et al.*, 2001) and (Singh *et al.*, 2001) in multi-locational trials in northern Nigeria (Table I). The N balance estimates of (Singh *et al.*, 2003) suggest that return of N in soybean haulms is approximately 10 to 15 kg/ha.

To improve the benefit to the soil a variety that puts more N in vegetation is preferred although the farm household may require more grain. Data derived from (Schulz *et al.*, (2001) show that aboveground residue dry matter increases with maturity class of the cowpea (Table II). Therefore the benefit of cowpea rotation can be expected to increase with duration of the variety, even if the harvest index remains constant. Generally, however, the harvest index also decreases with increasing maturity cycle. Stoop and van Staveren (1982) demonstrated that the impact on subsequent millet grain yield increases with the increasing maturity cycle of preceding cowpea.

Table I. N balance (kg/ha) of soybean crops (with haulms returned) in multi-locational trials (3 or 4 sites per trial) in northern Nigeria.

Soybean	Maturity	Trial	Trial	Trial
Line		1	2	3
TGx 1485-1D	early	-5.4	-7.2	-12.2
TGx 1805-2E	early	-3.9	----	----
TGx 1681-3F	early	-7.5	----	----
TGx 536-2D	medium	----	----	-2.6
TGx 1809-12E	medium	+1.7	----	----
TGx 923-2E	late	+9.5	----	+1.6
TGx 1670-1F	late	+1.5	+3.8	+10.9

Trial 1 = Singh *et al.* (2003); Trial 2 = Singh *et al.* (2001); Trial 3 = Ogoke *et al***.** (2003).

Table II. Aboveground dry matter (t/ha) of cowpea and soybean as a function of maturity class and insecticide treatment (number of observations in parentheses).

Maturity class	------------- Cowpea -----------------		Soybean
	+ Insecticide	- Insecticide	
Early	2.2 (29)	2.3 (34)	1.4 (289)
Medium	2.5 (73)	3.9 (41)	1.7 (302)
Late	3.3 (99)	3.9 (69)	1.9 (227)

Source: Schulz et al (2001).

The benefits of Mucuna to soil fertility and weed suppression are related to total biomass accumulation, which is partly a function of Mucuna genotype (in addition to soil conditions and length of growing period). Relatively early genotypes exist that mature in 3 to 4 months but comparison with late maturing types indicates that their ability to accumulate biomass and cover the soil can be expected to be less than that of late maturing types. Such varieties have been shown to be less effective in controlling weeds and providing N to subsequent maize (Figure 3).

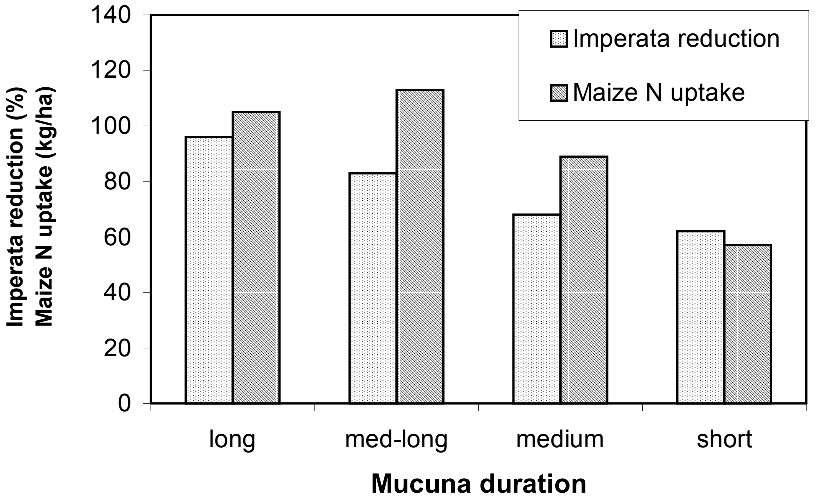

Figure 3. Effect of Mucuna variety duration on speargrass suppression and subsequent maize N uptake from review by Carsky *et al.* (2001c).

Adequate P nutrition

It is clear that adequate P is important for BNF in legumes and therefore it is a pre-condition for a positive effect of legumes in the soil-plant system. It was also hypothesized that adequate soil P would determine the N balance in the soybean crop. Ogoke *et al.* (2003) found that soybean residue N (haulms plus litter fallen before harvest) increased from 25 kg/ha without P applied to 39 kg/ha with N applied and N balance increased accordingly (table III). Sanginga *et al.* (2000) found apparent N balance to be improved by application of P in "P-responding cowpeas". This benefit is believed to be related to improved nodulation as P application doubled or tripled nodule numbers and nodule fresh weight. The importance of P supply was also shown in a study of cowpea-maize rotation in Nigeria (Carsky *et al.*, 2001a) in which the effect of cowpea rotation was not important until plant available P was increased to 9 g/kg. Muleba (1986) also showed the benefit of P application to cowpea in rotation with maize in Burkina Faso, although the treatment structure does not allow one to be sure how much of the beneficial effect was due to N contribution from cowpea biomass and how much was due to residual applied P. Carsky *et al.* (2001b) showed that maize dry matter after P-amended Mucuna was increased more than after P-amended maize, suggesting that P application increased the N benefit of the legume. This effect was even greater for lablab (*Lablab purpureus*).

Table III. N balance (kg/ha) as a function of P application to soybean (mean of 4 lines) and return of soybean haulms in three sites in the long mono-modal rainfall zone of Nigeria (Ogoke *et al.*, 2003).

P applied (kg/ha)	+ haulms	- haulms
0	-9.3	-18.2
30	+2.4	-13.8
60	+5.2	-10.4

In modern agriculture P fertilizer application is often guided by soil testing and comparison with published critical levels. A synthesis of results from the savannas of Nigeria suggests that the critical level of plant available P for soybean is approximately 10 ppm (Figure 4). The critical level of plant available P for cowpea has been estimated at 10.6 g/kg by Aune and Lal (1995), but this is the same critical level used for all grain legumes and therefore could be refined for different crops and soils. A preliminary attempt to estimate the plant available P critical level for Mucuna reported by (Carsky *et al.*, 1998) gives a value between 5 and 10 ppm.

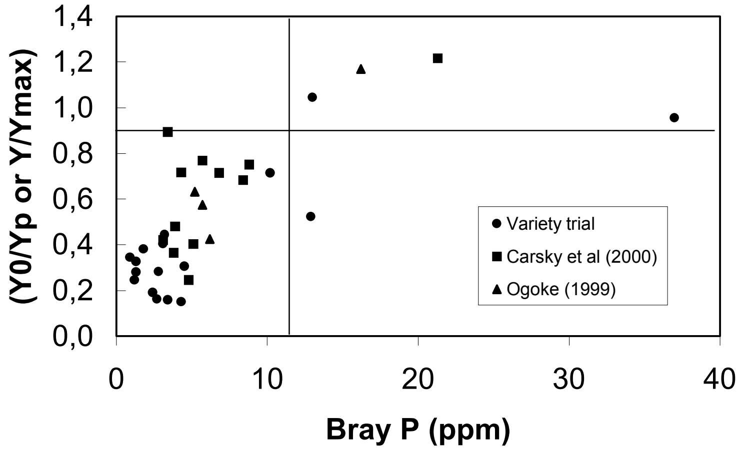

Figure 4. Soybean critical plant available P level for soybean in the savanna zone of Nigeria from Carsky, unpublished data, 1997;Carsky *et al.* (2000 ; Ogoke (1999).

It has been reported that some legumes improve bioavailability of sparingly soluble soil P and the same benefit has been extended to sparingly soluble P fertilizers (Vanlauwe *et al.*, 2000ab). Mucuna may help make soil P or rock P more available to plants. On P-fixing soils in the highlands of Cameroon, the data of Yamoah *et al.* (1996) suggested that the P fertilizer requirement of maize and beans might be reduced through Mucuna rotation. Yield of maize grain without P following Mucuna was similar to the control (without Mucuna) with 150–200 kg P/ha. Similarly, Mucuna fallow was implicated in enhancing release of P from rock phosphate (RP) resulting in increased Olsen P compared to maize or lablab treatments (Vanlauwe *et al.*, 2000b). Scientists are currently gathering evidence that some lines of cowpea increase availability of P from rock phosphate (Ankomah *et al.*, 1995).

Smallest possible interval between legume and non-legume

The time between cowpea harvest and cereal planting is obviously important. One only needs to look at the relatively large effect of cowpea rotation in the trials of Dakora *et al.* (1987) and Carsky *et al.* (2001a) when cowpea was grown in the first growing season followed immediately by maize in the long mono-modal rainfall zone. Thus cowpea cropping in the first part of the growing season should be considered. However, farmers may be reluctant due to possible loss of cowpea grain quality and the need to produce cereals first every year for food.

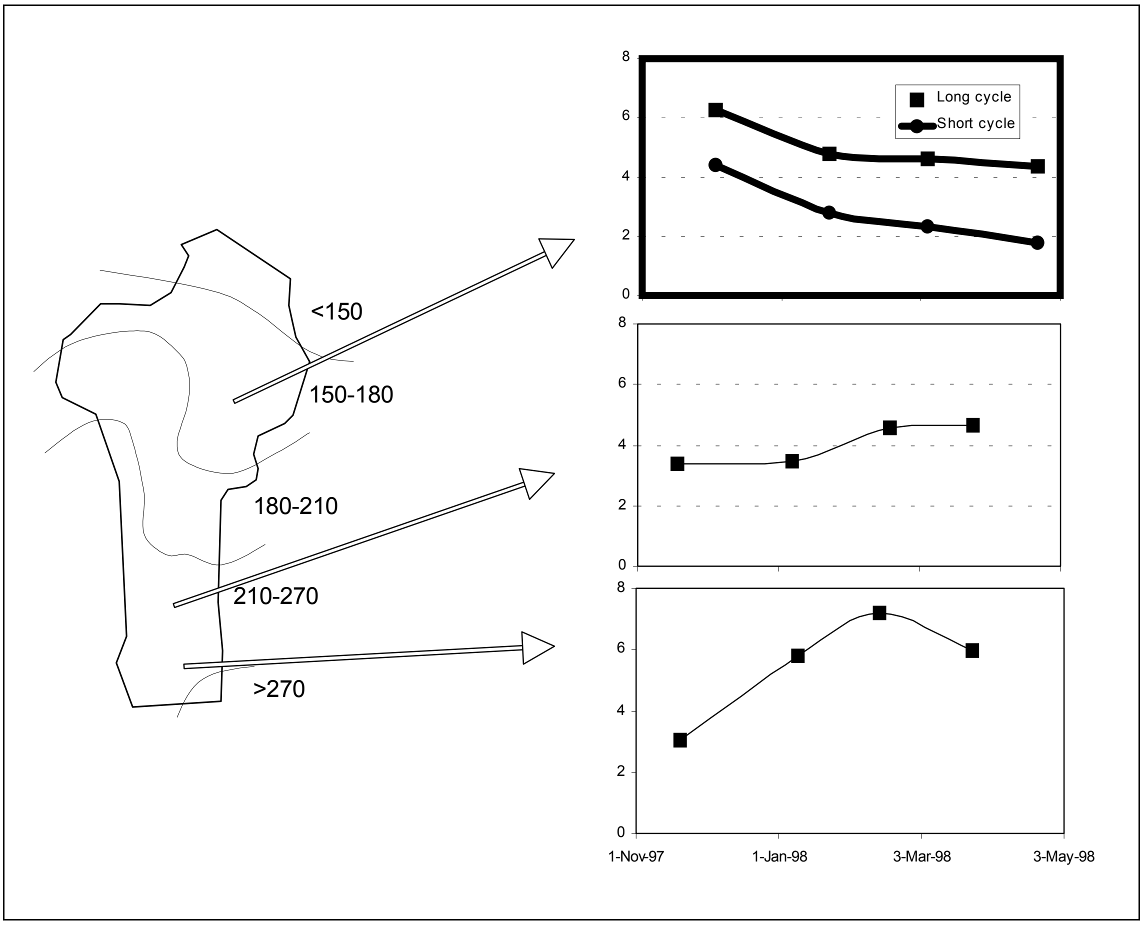

Figure 5. Evolution of Mucuna dry matter during the dry season along north-south transect in the Benin Republic, adapted from (Carsky and Eteka, 2000).

Mucuna is generally grown during the second season and into the dry season during which it senesces. Persistence of Mucuna dry matter during the dry season will help protect the soil and suppress emerging weeds. Carsky *et al.* (1998) observed the disappearance of Mucuna residue at a rate of approximately 1 t/ha during the dry season near Bauchi in northern Nigeria (195 day dry season) so that almost nothing was left on the soil surface at the time of maize planting. Rates of disappearance were lower at Ina and Parakou in northern Benin with a 165 day dry season (Carsky and Eteka, 2000). In the same study along a north–south transect in Benin (Figure 5), new growth in southern Benin with a dry season of approximately 100 days and sporadic rains compensated for the disappearance of Mucuna residue. Dry season survival of Mucuna was also observed by Burle *et al.* (1992) in the savannas of Brazil with a dry season of approximately 100 days. Therefore, Mucuna fallow can be most effective where the dry season is less than four months.

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