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PIGEONPEA IN SIMULTANEOUS FALLOW-CROPPING SYSTEMS IN THE SUBHUMID FOREST-SAVANNA MOSAIC ZONE OF WEST AFRICA

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SUMMARY

The potential of pigeonpea (*Cajanus cajan* (L.) Millsp.) as a simultaneous fallow component in cropping systems is unique in that, being a shrubby grain legume, it combines food production with ease of establishment, fast growth and high biomass productivity. A study was carried out under on-farm conditions at three different sites in southern Bénin, West Africa over two years to evaluate the biomass productivity and recycled nutrients of a local pigeonpea cultivar, managed as annual hedgerows. Pigeonpea was sown between a standard cassava–maize intercrop and compared with two other agroforestry systems and annual intercrops with and without mineral fertilizer. The number of cuts taken at a height of 1 m was doubled from two in 1991–92 to four in the 1992–93 season, leading to an increase in total cut dry matter by a factor of eight (1908 g m^{-2}) and cut leaf dry matter by a factor of fourteen (1317 g m^{-2}) in 1992–93. There were no trade-offs in subsequent dry grain (9.5 g m^{-2}) and firewood yields (96.2 g m^{-2}) for cutting hedges earlier and more often during the second year, despite much lower precipitation. In pigeonpea recycled nutrients, N, P, Ca, Mg and K, increased proportionally to cut dry matter yields. Yield increases over two years with pigeonpea were highest among all evaluated cropping systems for maize (+150%) and significant for cassava (+66%). Pigeonpea as a simultaneous fallow component in cassava–maize intercropping, can help to sustain moderate yields of maize and cassava, provided that insects, nematodes and diseases do not lower its high biomass productivity with continued cropping after two years.

INTRODUCTION

In many parts of West Africa, much shortened fallow periods are necessary to extend food production for a rapidly increasing population. Traditional bush-fallowing today relies largely on soil mining and crop yields are therefore declining progressively (Leihner *et al.*, 1993; Stahr *et al.*, 1993). Simultaneous fallow-cropping systems, that is, cropping systems that combine beneficial fallow vegetation and field crops in a field at the same time, have been considered for their potential to conserve nutrients and sustain crop yields (Gichuru, 1991; Kühne, 1993; Leihner *et al.*, 1993; Stahr *et al.*, 1993). The simultaneous fallow component is often a shrub or tree species that is cut at regular intervals to recycle nutrients to crops. Simultaneously, its competition for crop resources should be

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minimal (Böhringer *et al.*, 1994; Daniel *et al.*, 1991; Leihner *et al.*, 1993). The pigeonpea (*Cajanus cajan* (L.) Millsp.) is unique in that, being a shrubby grain legume, it combines food production with ease of establishment, fast growth, high biomass productivity and good local acceptance (Boehringer and Caldwell, 1989; Daniel and Ong, 1990). Pigeonpea was evaluated as a simultaneous fallow component in Zambia (Boehringer and Caldwell, 1989), in Hawaii (Böhringer *et al.*, 1994), in India (Daniel *et al.*, 1991; Jain *et al.*, 1987; Odongo *et al.*, 1991), and in Bénin (Kühne, 1993). Since all research was carried out on-station and in small plots, little is yet known about the performance of pigeonpea under real farming conditions, for example, in field-size plots grown with a traditional intercrop and under local management. It was hypothesized that pigeonpea could help to intensify cropping in the region by allowing prolonged cropping periods and sustaining yields.

The objectives of this study were: (1) to evaluate a local pigeonpea cultivar as a simultaneous fallow component in different environments under on-farm conditions, (2) to evaluate the effect of cropping year and cutting regime on its productivity, and (3) to evaluate its contribution to nutrient cycling and effect on the productivity of a cassava–maize intercrop in comparison to other cropping system alternatives.

Large-scale experiments were carried out at three different sites in southern Bénin between 1991 and 1993 with pigeonpea being compared with two other systems involving *Gliricidia sepium* and *Flemingia macrophylla* and two annual cassava–maize intercrops without simultaneous fallow components, one with and the other without mineral fertilizer applications. This paper concentrates on the results of pigeonpea; those of both other simultaneous fallow-cropping systems involving *G. sepium* and *F. macrophylla* are reported elsewhere (Böhringer and Leihner, 1997).

MATERIALS AND METHODS

The study was conducted at three village locations, Houeto, Attotinga and Aguagon, situated between latitude 6°27′N and 7°58′N and longitude 2° and 3°E in the Atlantique and Zou provinces of the Republic of Bénin, West Africa.

Mean monthly temperature, averaged over sites for the last 20 years, was 28.7°C. Rainfall distribution changes from bimodal at Houeto and Attotinga to unimodal at Aguagon. Total rainfall at the three study sites for the 1991–92 cropping season (March–February) was 1156 mm at Houeto, 1184 mm at Attotinga, and 960 mm at Aguagon; the respective values in the 1992–93 season were 844, 835 and 742 mm. Twenty-year averages of total annual rainfall at nearby weather stations of the three sites were 1244, 1156 and 1099 mm respectively (Böhringer and Leihner, 1997).

Soils at Houeto and Attotinga are classified as Ferrali-Haplic Acrisols and locally known as 'terre de barre' (Stahr *et al.*, 1993). Houeto was more degraded with $\mathrm{pH(CaCl_2)} = 4.9$, $\mathrm{K_{ex}^{+}}$ (mg 100 g^{-1}) $= 0.15$, $\mathrm{Ca_{ex}^{2+}}$ (mg kg^{-1}) $= 3.46$,

$\mathrm{Mg}^{2+}_{\mathrm{ex}}$(mg kg^{-1}) = 1.46, CEC(mmol$_c$ kg^{-1}) = 24.0, $\mathrm{P}_{\mathrm{BRAY}}$(mg 100 g^{-1}) = 0.21, N_t(g kg^{-1}) = 0.52, C_t(g kg^{-1}) = 4.81 and C:N ratio = 9.3 in the topsoil (0–23 cm). The respective values for the less-degraded site at Attotinga were 5.3, 0.38, 7.01, 1.12, 28.9, 0.26, 0.38, 5.21 and 13.7 (0–30 cm). The soil at Aguagon is classified as a Ferric Lixisol with pH($\mathrm{CaCl_2}$) = 5.6, $\mathrm{K}^{+}_{\mathrm{ex}}$(mg 100 g^{-1}) = 0.40, $\mathrm{Ca}^{2+}_{\mathrm{ex}}$(mg kg^{-1}) = 8.15, $\mathrm{Mg}^{2+}_{\mathrm{ex}}$(mg kg^{-1}) = 0.82, CEC(mmol$_c$ kg^{-1}) = 41.4, $\mathrm{P}_{\mathrm{BRAY}}$(mg 100 g^{-1}) = 0.13, N_t(g kg^{-1}) = 0.33, C_t(g kg^{-1}) = 4.07 and C:N ratio = 12.3 in the topsoil (0–33 cm) (C. Fritz, Universität Hohenheim, personal communication; Stahr *et al.*, 1993).

Bush-fallow rotational agriculture is the major land-use system in Bénin and the main crops cultivated are maize, cassava, cowpeas, peanuts and yams. Local cultivars of pigeonpea are tall, erect and late maturing, and a common sight along field edges and around homesteads. Pigeonpea grain is sold throughout the year on local markets and consumed much like dry cowpeas.

At each site, 20 plots ranging in size between 400 and 576 m^2 were laid out as randomized complete blocks with five treatments and four replications. Three simultaneous fallow-cropping systems were compared with two maize–cassava intercropping systems without hedgerows, one an unfertilized control and the other receiving annual applications of 9.0 g N, 3.9 g P and 7.4 g K m^{-2}. Treatments with simultaneous fallow components were: alley cropping with *G. sepium* and *F. macrophylla* mixed within hedgerows; block planting with *G. sepium* and *F. macrophylla* mixed within hedgerows; and alley cropping with pigeonpea managed as annual hedges (Leihner *et al.*, 1993; Böhringer and Leihner, 1997).

Experiments were managed as researcher-controlled on-farm trials, but all field operations were carried out by villagers using local techniques. Total and relative plant populations of crops and trees were identical in all plots, but plant spacings of components varied between treatments. Treatment differences in spacing were thought to be similar to farmers' choices at planting in deciding how to arrange a fixed number of plants in a limited area. An intercrop of the open-pollinated maize cultivar TZSR-W at 2.5 plants m^{-2} and the tall, erect, late-branching cassava cultivar Agric Local at 0.8 plants m^{-2} was established with the onset of rains at each location (Table 1). Low crop populations were chosen because similar densities are used by farmers in the region and the control was intended to represent farmers' conditions. Major field activities for maize, cassava and pigeonpea are summarized in Table 1 for two cropping seasons.

In both alley cropping treatments, that is with either *G. sepium* and *F. macrophylla* or with pigeonpea, hedges were spaced at 4-m intervals in the field. The same number of hedgerows as in both alley cropping systems was sown in the third treatment involving *G. sepium* and *F. macrophylla*, but tree rows were concentrated in a solid-planting at one side of the plot and were spaced 1 m apart. Between blocks of both components, a 1.5-m wide corridor was left unplanted. Dry matter (DM) cut from the trees was carried over from the tree blocks to mulch the adjacent block of crops (Böhringer and Leihner, 1997). For

Table 1. *Field activities for maize, cassava and pigeonpea* (Cajanus cajan) *at three locations in southern Bénin over two cropping seasons (1991–93)*

	Days after planting	
	1991–92	1992–93
Planting maize, cassava and pigeonpea	Onset of rains†	Onset of rains‡
Maize thinning	26	25
Weeding	25, 49, 146, 241	21, 45, 150
Maize harvest	127	130
Pigeonpea cuts	183	93, 131, 183
Cassava harvest	337	330
Pigeonpea grain harvest§	290–351	275–320
Pigeonpea final cut	365	365

†25/4/91 at Houeto, 27/3/91 at Attotinga and 17/4/91 at Aguagon; ‡ 22/4/92 at Houeto, 14/4/92 at Attotinga and 7/5/92 at Aguagon; § several grain harvests varying with location and differences in rainfall and soils and due to local cultivar being indeterminate.

pigeonpea, a cream-seeded, indeterminate local cultivar from Bénin was direct sown at a within-row spacing of 0.125 m.

Maize and cassava were planted in all treatments at each location at the same time (Table 1). In both alley cropping systems, one row of maize was planted 0.75 m away from hedges and two cassava rows were planted in the centre of the alleys with 1.0 m between rows and 0.75 m between maize and cassava. In the block planting system, maize and cassava rows alternated at 1 m distance. The within-row spacing for maize was 0.40 m in alley cropping and 0.57 m in blocks at two plants per hill, whereas for cassava it was one plant per station at within-row spacings of 0.60 m and 0.88 m (in alley cropping and blocks respectively). Plant arrangement in cassava–maize intercrops with and without fertilizer was as follows: for maize 1.5 m between and 0.40 m within rows at two plants per station and for cassava double rows in between maize at 0.50 m distance and 1.25 m within row (Leihner *et al.*, 1993).

The exhausted soil at Houeto required a blanket dressing of 14.5 g N, 4.0 g P, and 16.8 g K m^{-2} to all plots at the beginning of the second cropping season.

Maize and cassava plants within a sample cropping area of 12 m^2 each were harvested and weighed. For pigeonpea, two hedge samples of 10 m in length in each plot were used for stand count and DM determinations. Hedges were cut with a cutlass 1.0 m above the ground twice in 1991–92 and four times in 1992–93 (Table 1). After bulk-cut fresh matter (FM) was taken, cuts from six representative plants were separated into leaves plus petioles and stems. Sub-samples in each plot for drying had 500 g leaves and 800 g stems. DM yield calculations (g m^{-2}) were based on FM of separated plant parts and bulk-cut FM. All cut material was evenly spread in the plot as mulch. Mature pods were picked by hand several times at the end of the dry season each year (Table 1) and shelled to determine total dry grain yield (g m^{-2}). At the final cut (Table 1), stubble DM from ground

Table 2. *Cut dry matter (DM) and cut leaf DM yields (g m^{-2}) of a local pigeonpea cultivar at three locations in southern Bénin at 183 days after planting in 1991–92 and 1992–93*

	Location			
Year	Attotinga	Houeto	Aguagon	s.e.
		Cut DM		
1991–92	197	188	235	24
1992–93	1192	593	997	235
		Cut leaf DM		
1991–92	85	67	82	12
1992–93	863	456	722	179

level to a height of 1 m was weighed as for the cut samples, but main stems were later exported as firewood. Dry leaf and stem sub-samples were analysed for N, P, Ca, Mg and K at the Landesanstalt für landwirtschaftliche Chemie of the Universität Hohenheim using VDLUFA-methods (Naumann and Basler, 1976). Similar nutrient analyses were carried out for crops at harvesting and for *G. sepium* and *F. macrophylla* at each cut to calculate overall above-ground nutrient balances, that is, recycled biomass minus exported harvests of all plant components in each treatment (Böhringer and Leihner, 1997; Leihner *et al.*, 1993).

RESULTS

Pigeonpea dry matter and grain yield

Total DM yields from all cuts did not differ between environments, but differed significantly between years. Mean total DM and leaf DM from four cuts were higher (1908 and 1317 g m^{-2} respectively) in 1992–93 compared with 236 and 89 g m^{-2} from two cuts in 1991–92 respectively. Overall proportions of leaf in the cut DM amounted to 69% in 1992–93 and 38% in 1991–92. Analysis by years showed no differences in total DM between cuts or environments nor was there any interaction between cuts and environments in 1991–92. (Table 2). The effect of environment was important for leaf DM alone. Timing of the first cut in 1991–92 matched the third cut in 1992–93 (Table 1) and their combined ANOVA revealed significant effects of years and environments. Yields were always higher in 1992–93, and those at Houeto were always lowest (Table 2). At the final cut at 365 days after planting (DAP) the effect of year on cut DM was significant, but environment and the interaction with years gave no response. DM in 1992–93 was 403 g m^{-2} with 179 g m^{-2} of leaves and the respective values for 1991–92 were 32 and 13 g m^{-2}. Stems in the stubble did not differ between years nor with environments and produced 96 g DM m^{-2} of firewood overall. There was no effect of cropping year, environment or their interaction on dry grain yield which amounted on average to 9.5 g m^{-2}.

Above-ground nutrient uptake and cycling

In the first year, nutrient contents in the leaves were similar for all elements between environments and cuts, except for P between cuts; leaves at the final cut contained 0.295% P against 0.233% at 183 DAP. Stem nutrient contents were alike for all elements except K; values on both Acrisols were similar, but much higher on the Lixisol (1.18 compared with 0.81% on average); also, stems were richer in K at the first cut than at 365 DAP (1.15 compared with 0.69%). In the second year, leaf N, leaf Ca, leaf Mg, and stem K differed significantly between environments and leaf Mg, stem N, stem P, and stem K were significantly different between cutting dates. Total balances over two years between above-ground recycled nutrients (in leaves, stems and leaf litter) and those exported from the system (in mainstems for firewood and pods) were positive for N, P, K, Ca and Mg being 71.1, 17.0, 12.8, 15.3 and 15.7 g m^{-2} respectively. Values for leaf litter were based on three-year results by Kühne (1993), who with the same local cultivar, recorded mean DM quantities of 215 g m^{-2} with concentrations of 1.96% N, 0.09% P, 1.08% Ca, 0.46% Mg, and 0.22% K. Values for pods were also based on nutrient contents reported by Kühne (1993): 2.37% N, 0.28% P, 0.18% Ca, 0.18% Mg, and 1.09% K. Table 3 shows recycled nutrients in cut leaves and stems (excluding leaf litter) across environments at each cut in both cropping seasons. Balances between above-ground nutrients recycled by crops and simultaneous fallow components together and harvests exported are given for all

Table 3. *Mean recycled nutrients* (g *m*$^{-2}$) *in dry leaves and stems of pigeonpea cut at different days after planting (DAP) at three locations in southern Bénin during two cropping years (1991–93)*

	Nutrients				
DAP	N	P	C	Mg	K
			1991–92		
93	—†	—	—	—	—
131	—	—	—	—	—
183	5.33	0.38	1.60	0.56	2.36
365	0.77	0.05	0.28	0.09	0.32
Total	6.10	0.43	1.88	0.65	2.68
s.e.	0.02	0.05	0.21	0.07	0.23
			1992–93		
93	7.33	0.52	1.73	0.63	3.32
131	11.42	0.97	2.67	1.03	6.77
183	30.05	2.29	6.81	2.46	13.57
365	9.29	0.69	3.44	1.16	3.52
Total	58.09	4.47	14.65	5.28	27.18
s.e.	3.22	0.19	0.81	0.23	1.68

†Not cut.

Table 4. *Above-ground biomass recycling balances of the major nutrients, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) (g m^{-2}) in five cropping systems at three locations in southern Bénin after two cropping seasons (1991–93)*

	Nutrients				
Cropping system†	N	P	K	Ca	Mg
Control	−2.596	−0.774	−2.457	−0.359	−0.367
Fertilizer‡	−6.900	−1.232	−7.177	−2.944	−2.670
Alley cropping§	−1.065	−0.582	−1.804	−0.792	−0.497
Pigeonpea¶	+59.703	+4.1491	+25.728	+15.191	+5.414
Block planting§	−0.060	−0.402	−0.102	+0.159	+0.124

†Use of plant parts of crops in all cropping systems were: maize recycled = stems + leaves + husks; maize harvested = cobs + grain; cassava recycled = leaves + petioles + stem tops + lignified basal stems; cassava harvested = main stems + roots; ‡ 9.0 g nitrogen, 3.9 g phosphorus and 7.4 g potassium m^{-2}; § including recycled leaves and stems from *Gliricidia sepium* and *Flemingia macrophylla* cuttings (> 1 m height) ¶ including recycled leaves and stems from pigeonpea cuttings (> 1 m height) and pigeonpea main stems (< 1 m height) and pods.

five cropping systems in Table 4. Balances were negative in annual intercropping with fertilizer and pigeonpea was the only cropping system recycling large surpluses in above-ground biomass for all five elements analysed.

Crop yields

Average maize grain yields were higher in 1992–93 in all the five treatments (Table 5). Increases between the 1991–92 and the 1992–93 season were highest in the pigeonpea cropping system (+150%) and important in all other treatments except alley cropping with trees. Cassava dry root yields between years could be raised only with the pigeonpea system (+ 66%), with losses or small gains being noted in all other cropping systems. Root yields in 1991–92 were lowest in the pigeonpea cropping system, but ranked second in 1992–93, giving pigeonpea a significant advantage over the check and block plantings.

DISCUSSION

Pigeonpea productivity and management

Overall DM yields demonstrated clearly the advantage of cutting pigeonpea hedges earlier and more often (Table 1). Total cut DM increased by a factor of 8 and cut leaf DM by a factor of 14 in 1992–93. Early cuttings in Bénin coincided with longer days which also favoured vegetative growth in photoperiod sensitive pigeonpea (Daniel and Ong, 1990). This explained why DM productivity declined at cuts taken later than September in both years (Tables 1 and 3). Stem proportions were substantially lower in earlier cuts, yielding mulch of higher quality (Table 5; Böhringer *et al.*, 1994). The effect of early cutting on cut DM yields was more significant in 1992–93 with the much lower total precipitation,

Table 5. *Maize dry grain yield and cassava dry root yield (g m^{-2}) in five cropping systems in southern Bénin over two cropping seasons, 1991–92 and 1992–93*

	Year			
Cropping system†	1991–92	1992–93	Mean	s.e.
	Maize grain yield			
Control	74.8	128.7	101.7	20.3
Fertilizer	130.6	238.3	184.5	18.0
Alley cropping	72.9	78.3	75.6	16.2
Pigeonpea	52.2	130.5	91.4	21.8
Block planting	62.4	108.2	85.3	18.0
Mean	78.6	136.8	107.7	8.6
s.e.	20.9	16.7	13.6	
	Cassava root yield			
Control	318.4	307.7	313.0	35.3
Fertilizer	577.5	509.6	543.6	68.1
Alley cropping	322.8	321.8	322.1	41.7
Pigeonpea	236.2	392.3	314.2	28.7
Block planting	273.7	279.4	276.5	27.8
Mean	345.7	362.2	354.0	19.5
s.e.	38.6	46.9	30.8	

†See Table 4 for details of cropping systems.

approximately 300 mm less across locations than in the first year. This underlines the potential of pigeonpea even in lower rainfall environments (Daniel and Ong, 1990; Daniel *et al.*, 1991; ICRISAT, 1987). Differences between locations (Table 2) also point to the influence of soils on DM productivity. A comparison of cut DM on both Acrisols in 1992–93 shows yields at Attotinga to be approximately twice as high as those at Houeto, corresponding to lower pH, $K^{+}{}_{ex}$, $Ca^{2+}{}_{ex}$, CEC, P_{BRAY}, C_t and C:N in the Houeto soil at the beginning of the experiment. Leaf DM yields were also significantly higher on the Lixisol in 1992–93 underlining the role of good K and Ca supplies for high DM productivity of pigeonpea. Likewise, experiments in Hawaii (Böhringer *et al.*, 1994) showed effects of soil fertility to be more important than climate in determining DM productivity.

Most important for farmers are the results at the final cut each season: the cutting regime and hence cut DM production influence neither grain nor firewood yields of pigeonpea, making labour for cutting the only direct additional cost to the farmer in order to obtain more mulch. In other experiments with perennial pigeonpea it was reported that drastic yield depressions occurred after one year of cutting (Boehringer and Caldwell, 1989; Böhringer *et al.*, 1994; Daniel and Ong, 1990; Kühne, 1993). This annual character was the reason for resowing every year, especially when farmers judged the cost of re-establishing hedges to be negligible. Neither of the systems with mixed hedges of *G. sepium* and *F. macrophylla* produced any food or firewood during the time under study. Therefore it was only pigeonpea that was able to generate some payback after the first year of cropping and this advantage could help to improve its acceptability among farmers for planting as a simultaneous fallow component.

In 1992–93 total cut DM of the local cultivar Bénin compared well with others reported for improved genotypes (Boehringer and Caldwell, 1989; Böhringer *et al.*, 1994; Kühne, 1993; Odongo *et al.*, 1991). However, Kühne (1993), who used the same local cultivar in a similar environment, obtained much lower cut DM and firewood yields and this may have been due to the following management differences in his study: (1) lower plant stand (2 compared with 8 plants m^{-2}, Natarajan and Willey, 1981; ICRISAT, 1987), (2) lower cutting height (0.75 m compared with 1.0 m, Bahar and Prine, 1982) and (3) later cutting (347 compared with 183 or 93 DAP, Daniel and Ong, 1990). However, the dry grain and wood yields of cultivars in this experiment were low compared with yields of other cultivars under optimum management and inputs in India (Jain *et al.*, 1987; Odongo *et al.*, 1991). Differences were especially large for grain but high yields in India were obtained with regular applications of insecticides and the yield potential of the local Bénin cultivar needs to be evaluated with comparable inputs (ICRISAT, 1987; Natarajan and Willey, 1981; Odongo *et al.*, 1991), before improved cultivars are considered for introduction.

Nutrient cycling and interactions with crops

The higher K content in the stems of pigeonpea at Aguagon in both years, compared with the Acrisol sites at Houeto and Attotinga were due to the greater availability of K in the Lixisol at Aguagon, and the same was true for the higher Ca contents in the leaves in 1992–93 (Stahr *et al.*, 1993). Since cut leaf DM was also significantly greater at Aguagon in 1992–93, it appears that both elements were especially deficient in supply at the degraded Acrisol site at Houeto, despite having received a blanket dressing of 14.5 g N, 4.0 g P and 16.8 g K m^{-2} in 1992. Furthermore, yields were similar on both Acrisols in the first year and therefore the effect of blanket fertilization on cut DM yields at Houeto in the second year was negative. A mechanism for explaining this phenomenon could be a lowered overall N efficiency of pigeonpea due to inhibited biological nitrogen fixation caused by this early fertilizer application (Amand and Mughogho, 1985; ICRISAT, 1987). Above-ground nutrient balances across years demonstrated clearly the value and potential of pigeonpea to recycle significant amounts of nutrients while providing modest amounts of food and firewood to the farming family at the same time. In comparison, recycled quantities from *G. sepium* and *F. macrophylla* together could not even balance above-ground nutrient losses from the system which accrued from crop harvests after two years. This alone makes it very unlikely that either of the tree species, used in simultaneous fallow-cropping systems, could help to stabilize crop yields in the shorter term, marking them as a long-term and rather questionable investment for farmers. With pigeonpea, the sharp increase in recycled nutrients in 1992–93 came as a direct result of cutting hedges earlier and more often, highlighting the potential impact of simple changes in pigeonpea management on overall nutrient cycling within cropping systems.

However, a synchronization of nutrients recycled by pigeonpea with the demands of maize was not possible, since pigeonpea was resown each year and hedges needed 93 DAP for establishment in the second year before they could be cut. Greatest nutrient quantities from cut material were harvested in both years at 183 DAP, leaving more benefit from green manure to the remaining cassava. For farmers who placed emphasis on cassava in such intercropping systems, pigeonpea appeared to be a good simultaneous fallow component in stabilizing root yields. Although considerable quantities of nutrients were recycled to the system by pigeonpea, overall yield increases of maize and cassava in the second year were disappointing. Limited crop uptake of nutrients applied in the mulch may be explained by a combination of two factors: (1) bad timing between the date of cutting, the availability of recycled nutrients to crops (time of mulch decomposition) and peak crop demand, and (2) the occurrence of large nutrient losses particularly through leaching on the soils under study (Stahr *et al*., 1993). However, some beneficial residual effect of pigeonpea seemed to be noticeable on the yield of both crops in the second year. Here, recycled root biomass must have added considerable benefit every year (Gichuru, 1991) and this may have given annual pigeonpea another advantage over the simultaneous fallow-cropping systems with permanent tree hedges. The significance of the overall effect of pigeonpea on nutrient recycling needs to be verified over a greater number of cropping years in order to establish a positive relationship with system sustainability.

Limitations and further research needs

The overall performance of the local pigeonpea cultivar Bénin was surprisingly good in terms of DM productivity, but increased ratoon grain yields would be necessary for wider acceptance of the system; farmers judged grain yields low and attributed this to the new management practice of cutting pigeonpea. In the long term, major limitations to system productivity are likely to arise from increased nematode populations and disease occurrence (sterility mosaic, *Phoma cajanii*) in the field, since pigeonpea is known not to be self-compatible (Daniel and Ong, 1990; ICRISAT, 1987). In this situation improved resistant genotypes of pigeonpea could play a key role in sustaining yields in more continuous cropping. Ultimately, however, crop rotations would have to be introduced since permanent cassava–maize intercropping with pigeonpea would certainly have agronomic and socio-economic limitations over time.

CONCLUSIONS

Early and more frequent cutting of pigeonpea, managed as annual alley hedges, increased both DM and nutrient yields without decreasing grain and firewood yields later in the season. New cultivars could improve the system further if they matched the local cultivar in cut DM productivity and provided higher ratoon grain yields under similar low-input conditions. Long-term limitations to continuous cropping with pigeonpea are seen to be the increasing build-up of insects, nematodes and diseases in the field, resulting in significant decreases in pigeonpea productivity and yields. It appears unlikely, therefore, that pigeonpea alone could replace fully the need for fallowing in West African cropping systems.

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