The Role of Grain and Forage Legume Crops in Sustainable Agricultural Production Systems in Semi-Arid West Africa

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1. Background

Soils in semi-arid West Africa (SAWA) are low in organic matter (OM) content and severely deficient in nitrogen (N) and phosphorus (P) and, to some extent, sulphur and other nutrients (Milne 1968; Pieri 1985; Bationo *et al.* 1988). The bulk of agricultural production in the sub-region is carried out by resource-poor peasant farmers. The high demographic pressure of 2.8% per year has compelled them to expand agricultural production in marginal lands, to reduce fallow duration and/or to eliminate it altogether in order to meet their food and fibber needs and requirements. Cultivation is practiced virtually without any soil conservation or appropriate soil fertility restoration measures. This coupled with, annual bush-fire, wood cutting and felling--to meet domestic firewood demands as well as those for building houses and for furniture--, and grazing and browsing by livestock have destroyed vegetative cover and degraded ecosystems including agro-ecosystems. The overall result is a sever reduction of biodiversity, decreased agricultural productivity, and tendency to desertification of the sub-region. The degradation of agricultural production systems, have been depicted by a *per capita* food crop decline since mid-1970s. Africa, including the SAWA, is therefore importing food items, 12 million tons in 1995, to feed its people (Rosegrant 1995).

In this paper, we will briefly describe the current agricultural production systems in SAWA and review research and actual on-farm practice results using grain and forage legumes to:

- improve human and livestock nutrition;
- improve soil fertility and the productivity of subsequent cereal crops;
- enhance the intensification and integration of crop and livestock production systems for increased farmers' incomes and sustainable agricultural production systems; and finally
- draw lessons and technical recommendations.

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2. Current agricultural production systems

The SAWA covers three agro-ecological zones. These are the Sahel with 200 to 600 mm rainfall from late June to early September; the soils are predominantly Aridisols. The Sudan savannah (SS) zone with 600 to 900 mm rainfall from mid-June to late September; the soils are predominantly Alfisols. And the northern Guinea savannah (NGS) zone with 900 to 1250 mm rainfall from late May to mid October; arable lands include Alfisols, Inceptisols and Oxisols (Virmani *et al.* 1980).

Cereals millet, sorghum, maize and, to some extend, rice are staple food crops. They are mostly grown in upper-lands and supply over 75 to 80% of food energy to the majority of the people in the sub-region. Grain legume crops: cowpea, groundnut, bambara-nut, and recently soybean are also grown in upper-lands; they supplement cereal diets with cheap, quality protein. Livestock beef cattle, sheep and goats are abundant in the sub-region. With the exception of beef cattle, which milk is part of the daily diet of nomadic herders, livestock serve mostly the role of equity saving banks or are used for ceremonial events such as wedding, funeral, and religious feasts. There exists a high specialization among rural people in SAWA. Three distinct categories have been recognized (Matlock 1981) and include:

2.1. Herders

Herders are nomadic livestock raisers. Their base is in the Sahel agro-ecology. They practice transhumance in the Sudan savannah as well as in the northern Guinea savannah zones catering after their livestock. They virtually do not crop the lands. They live mostly on livestock products particularly milk, and do exchange animal products with food grain and vegetable crops from agricultural settlers.

2.2. Agricultural settlers

Agricultural settlers are sedentary people. They farm the lands raising food crops and some livestock at a small scale. They are found in all the three agro-ecologies of SAWA. They practice shifting cultivation though the fallow duration has been drastically curtailed to less than 5 years, if not eliminated altogether. They tether their livestock during the cropping season and free them roaming, grazing on crop residues and native grasses or browsing on shrubs and tree branches during the offseason. Farmers do also harvest millet, sorghum and maize fodder; grass straw; and cowpea and groundnut haulms, stock them and feed them to livestock in rudimentary pens during the offseason.

Crop diversity is narrow in the Sahel, mostly based on millet and cowpea and, to some extend, sorghum and groundnut. It is wide in the northern Guinea savannah where most of the crops described earlier are found in addition to cotton. And it is intermediate in the Sudan Savannah, where maize and cotton are less extensively cropped than in the Guinea savannah.

Agricultural settlers owning large herds prefer to contract nomadic herders for herding their animals rather than raising them themselves. So, livestock and crop production systems are not integrated in the sub-region.

2.3. Hand-crafters

These are blacksmiths, carpenters, weavers, and others. They produce tools such as hoes, machetes, carts, agricultural implements, etc. needed by farmers. They and agricultural merchants, from urban centres, support agricultural production by supplying some inputs to farmers and by marketing some agricultural produces.

2.4. Constraints to sustainable agricultural production

The high demographic pressure and the climatic change, experienced since mid-1970s: characterized by reduced and poorly distributed rainfall, coupled with the physical separation of livestock and crop production systems are constraining the natural ecosystems as well as the agro-ecosystems. This is particularly evident in the Sahel and in the Sudan savannah zones where, because of the inexistence of ownership of lands, pasture lands are exposed to overgrazing by livestock from both local agricultural settlers and nomadic herders. The soil improvement brought by livestock manure released in the ecosystems is nullified as overgrazing destroys the vegetative cover, exposes the soil and the newly deposited animal manure to direct sunshine, raindrop impact and wind blow. The results are excessive soil drying, destruction of soil OM and structure, increased runoff and soil water erosions, and increased wind erosions. If the pasture lands are located on the crest of a hill or on a hill slope, the subsequent increased water runoff and erosion ruin both, the pasture lands and field crops down the slope and in the bottom lands. The degradation of the bottom lands results mainly from the sediments brought from upper hill.

On the other hand, agricultural settlers are unable to increase incomes due to raising livestock. The inadequacy of penning and catering after livestock with appropriate feeding programmes, both quantity and quality wise, inhibits their rapid growth and efficient reproduction. As a result, the livestock production system is totally inefficient, characterised by slow maturation; high mortality rates; widely spaced calving, lambing and kidding; high abortion rates and low weaning percentages. Also farmers cannot take full advantage of raising livestock to maintain and/or restore their soil fertility, since a large proportion of manure is lost in the nature while livestock are roaming pasture lands, court yards, etc.

With the exception of the cotton crop--chemically fertilized in the Sudan and the northern Guinea savannah regions--and, to some extent, maize and groundnut crops--fertilized in some agro-ecologies--most cropping lands are virtually grown continuously unfertilized. The organic fertilization practiced by some farmers is inadequate to restore the depleted soil fertility. As a consequence, crop lands are being mined as reported by Bationo *et al.* (1997). These workers observed negative nutrient balances in most cropping lands in SAWA. The largest soil nutrient mining country being Nigeria with -

34 kg N ha^{-1}, -10 kg P_2O_5 ha^{-1} and -29 kg K_2O ha^{-1}; and the least one being Mali with -8 kg N ha^{-1}, -2 P_2O_5 ha^{-1} and -8 kg K_2O ha^{-1}

3. Importance of legume plants in human and livestock nutrition

Cereal grains provide most of daily food energy required for normal human productive live (digestive and metabolic functions, and physical and mental works, etc.) in SAWA. Their protein content is rather low, varying from 8 to 15%, and deficient in two essential amino acids, lysine and tryptophan. Grain legumes are, in contrast, high in protein contents; for example, cowpea and soybean have, respectively, 24-25% and 38-40% protein content (Bressani 1985). Their protein is, however, deficient in sulphur-containing essential amino acids: methionine and cystine. Mixtures of cereal-cowpea at the weight ratios: between 45 parts maize to 15 parts cowpea and 27 parts maize to 21 parts cowpea; and between 63 parts sorghum to 9 parts cowpea and 45 parts sorghum to 15 parts cowpea have been reported to provide a high quality protein for human diets (Bressani 1985). The same ratios involving cereal grains with either soybean or groundnut, bambara-nut or field bean are commonly recommended in combating children and pregnant women malnutrition.

Legumes' foliage have higher N content than cereal and native grasses' foliage prior to as well as after flowering and up to maturity. Yilala (1992) showed, in Burkina Faso, the N content of legumes remained > 20 g kg^{-1} dry matter (DM) up to maturity; whereas the reverse was true for grasses and cereal crops. The N content of the latter plants dropped to < 10 g kg^{-1} DM, a critical level for digestion by ruminants, after flowering. Also legume plants have more than twice the calcium content of grasses; the P contents of both groups of plants are, however, comparable (NRC 1989; Kuhl *et al.* 1993). Legume forages are thus used as protein supplement in livestock production. They increase the feed-intake of low and intermediate quality forages (Marston *et al.* 1998) including sorghum fodder and tropical grasses' straw (Yilala 1992), and thus improve their digestibility by ruminants. The DM and OM of faecal output of livestock, so fed, were reduced; while the N, P and K contents were increased (Yilala 1992) which improved their soil improvement attributes.

4. Importance of legume plants in soil fertility improvement

4.1. The cereal problem

In SAWA, because cereal grains provide up to 80% of energy required for human life, farmers give top priority to cereal crop production. Cereals are, therefore, sown first during the crop season, occupy the largest acreage in farm lands, and are grown either in pure-stand crops or in various crop mixtures. The mixtures include a combination of cereals of different maturity groups of different species or cultivars of the same species, cereals and grain legumes intercropping or relay-cropping systems. The relay-cropping systems, including the introduction of root and tuber crops, being more frequent in the moist northern Guinea savannah than in the Sudan savannah and the dry Sahel. When soil fertility declines, to avoid food shortage, farmers compensate the yield losses per unity land area by first expanding cereal acreage in marginal lands, and later on by curtailing the fallow duration, should they fall in short of available arable lands.

Cereals plants, like many other plants species, entertain a dual associative symbiosis with vesicular-arbuscular mycorrhizae (VAM). According to Bethlenfalvay and Linderman (1992), VAM are fungi that form a symbiotic relationship with plant roots. Their spores germinate, penetrate the root cortical cells and form specialized haustoria-like structures within the cells called ***arbuscules***. Metabolic exchanges between the fungus and host plant cytoplasm take place in the arbuscules. Characteristic vesicles form also in the cortical cells and function as storage organelles or as propagules in root fragments. The fungal hyphae of VAM extend from the root and interface with soil particles. Extraradical hyphae of VAM form a network exploring soil particles and bridging gaps across zones of nutrient depletion near plant roots. In the plant host-VAM symbiosis, the hyphal network functions in nutrient and water uptake and translocation, including the mobilization of nutrients such as P, copper (Cu), zinc (Zn), and others from soil-unavailable pools (Barea and Azcon-Aguilar 1983; Sylvia 1990; O'Keefe and Sylvia 1991; Thompson 1991).

By improving the nutrition of the host plant, the VAM symbiosis impacts the physiology of its host including the soil microbial and faunal activities in the root surroundings. In deed, the increased uptake of P and other nutrients stimulates the host photosynthesis and the export of C-metabolites to roots (Brown and Bethlenfalvay 1988; Jackobsen and Rosendall 1990). This changes the quality and the quantity of root exudates and the subsequent composition of micro-organisms in the rhizosphere, also redefined as mycorrhizosphere (Rambelli 1973; Linderman 1988).

Cereal crops are also renown for their high sensitivity to allelopathy, or autotoxicity (Cochran *et al.* 1977; Kaspar *et* al. 1990). Their seed germination, seedling growth and development, and plant productivity are impaired by the presence of their own crop residues or residues of related species decaying in the growing media. This could result from either chemical toxins released in the rhizosphere, or to the accumulation --selection-- of deleterious bacteria and other micro-organisms--related to decaying cereal residues--, or both. Thus, in addition to promoting *Striga hermontica* (Del.) Benth. infestations (see review by Berner *et al.* 1996 a, b), continuous cereal cropping in the same field is detrimental to its productivity in SAWA (Tetebo *et al.* 1992; Carsky and Berner 1997; Endondo 1997; Kombiok *et al.* 1997; Muleba 1999).

4.2. Legume soil improvement attributes

Legumes are unique among crop plants. They entertain a triple associative symbiosis including themselves for CO_2 fixation through photosynthesis, *Rhizobium* bacteria for biological N_2-fixation through root nodule activities, and VAM for soil nutrient and water uptake, including the mobilization of nutrients from soil-unavailable pools (Barea and Azcon-Aguilar 1983; Subb Rao and Krishna 1984; Thompson 1991). They can therefore grow and thrive under the limiting N and P regimes of unfertilized soils (Bethlenfalvay and Newton 1991; Barea *et al.* 1992). Some legume crops such as chickpea and pigeonpea, in addition to VAM symbiosis, can also improve their P nutrition through root exudates, which enable them to mobilize soil-unavailable calcium-bound P and iron-bound P (Ae *et al.* 1991 a, b). Legumes plants therefore enrich soils with OM well balanced in essential nutrients, stimulate favourable soil microbial and faunal activities and thereby improve agro-ecologies by restoring soil physical properties and fertility, particularly for N and P; they thus increase the productivity of the subsequent cereal crops (Hesterman *et al.* 1986; Edwards *et al.* 1988; Thompson 1991).

Of microbial activities stimulated by the tripartite symbiosis of legume plants, *Rhizobium* bacteria and VAM, it is worthy noting the free-living N_2-fixing bacteria in the genera *Azotobacter*, *Beijerinckia*, *Clostridium*, *Pseudomonas*, and *Azospirillum* (see review by Linderman 1992). These organisms mutually interact with VAM, though the precise mechanism has not been elucidated. VAM stimulate their activities; in turn, their presence in soil substrata, particularly for *Azospirillum* spp., promotes the colonization of legume plant roots by VAM and increases their productivity and that of several crops in the subsequent season. Because increases occur sometimes without evidence of increased N_2 fixation or increased N content in the plants, this has led some workers to suspect the involvement of plant hormones produced by free-living N_2 fixers (Allen *et al.* 1980, 1982; Barea and Azcon-Aguilar 1982). This appears to be supported by *Azotobacter vinelandii*, and *A. beijerinckii*, which have produced auxins, gibberellins, and cytokinins in culture (Azcon and Barea 1975). Their cell-free supernatants and whole cells have stimulated plant growth and VAM infection of lavender (*Lavandula spica* L.), tomato, and alfalfa (*Midicago sativa* L.) inoculated with VAM *Glomus mosseae* (Azcon *et al.* 1978).

Biologically N_2-fixing legume nodules and free-living bacteria are also known for their ability to reduce acetylene (C_2H_2), a competitor of N_2, to ethylene (C_2H_4), through nitrogenase enzyme activities (Giller and Wilson 1991). The release of the gas ethylene in the rhizosphere is certainly lethal to *Striga* spp. as this gas is used in *Striga* eradication programmes in the Unites States of America (Sand and Manley 1990). Berner *et al.* (1996 a, b) observed a consistent biotic suppression of *Striga hermontica* in all unsterilized natural soil samples studied in Nigeria. They termed this phenomenon as *natural soil suppressiveness* of *Striga*. Though some variability does exist, the same workers recognize also the *S. hermontica* control attributes of N_2-fixing legumes. This control as well as that of natural unsterilized soils can be speculated as resulting from natural releases of ethylene in the rhizosphere, which may also originate from legume nodules and free-living N_2-fixing bacteria during the crop season, and by only free-living N_2-fixers in the subsequent season in the absence of legume plants.

Legume plants by enriching soils with OM balanced in essential nutrients, particularly N and P, and stimulating soil microbial and faunal activities (Hesterman et al. 1986; Edwards et al. 1988; Thompson 1991; Muleba 1999; Muleba and Coulibaly 1999), may also contribute to disease control in addition to *Striga* control already discussed. Ratnayake *et al.* (1978) and Graham *et al.* (1981) observed a reduction of soluble carbohydrates from root exudates as a result of P fertilization. Since different pathogens have different requirements in root exudates, a change in these chemicals may impact their infectivity. Smith (1988) observed VAM colonized plants were healthier and more productive than non-VAM plants, and concluded that the primary effect of VAM on plant host-pathogen relationship was due to improved P nutrition.

N_2-fixing legume crops are, therefore, invaluable not only in soil fertility maintenance and restoration, but also in integrated pest management. Their inclusion in crop rotations and/or associations with cereals is likely to eliminate or mitigate conditions favouring cereals susceptibility to allelopathy --from their own crop residues--, and *Striga* and possibly disease infections. They, thus, have a positive impact on cereals in crop rotations. If their use is also combined with natural rock phosphate fertilizations, which are very abundant in the sub-region, they can restore the resource base of the agro-ecologies (Muleba 1999; Muleba and Coulibaly 1999), and thereby contribute to the development of a sustainable agriculture with low inputs.

5. Use of legume plants in improving soil fertility and crop productivity in SAWA

The N_2-fixation capacity of herbaceous legume plants, in the tropics, is variable; it can be as high as 395 kg N ha^{-1} (Table 1). It is functions of species, soil fertility--particularly availability of soil P and molybdenum nutrients--, cropping systems, crop growth duration and total biomass production (Mulongoy 1986; Giller and Wilson 1991). For grain legumes crops, groundnut (*Arachis hypogea*), pigeonpea (*Cajanus cajan*), soybean (*Glycine max*), field bean (*Phaseolus vulgaris*) and cowpea (*Vigna unguiculata*), the quantity of N_2 biologically fixed and injected in agro-ecosystems is a funtion of harvested N index (HNI), or the portion of fixed N contained in the seeds, and the manner the grain crop is harvested. Soybean has higher HNI than cowpea, its soil improvement attribute was shown to be less than that of cowpea, though it fixed more N than the latter crop (Eaglesham *et al.* 1982). Cowpea fixes less N_2 in intercropping with cereals than in its pure-stand cropping system (Mulongoy 1986).

5.1. Legume-cereals association cropping systems

Cereal intercropped with herbaceous legume crops yield comparably to or less than their pure-stand crop treatments in SAWA (Muleba *et al* 1985; Sawadogo *et al.* 1985; Endondo 1997; Toky and Renaud 1997). However, Kibreab (1992) observed millet intercropped with either an early cowpea, SUVITA-2, or an early cultivar of field bean

(*P. aureus*) out-yielded their pure-stand millet counterparts, in 1987, at two locations, Yalka and Kamsaoghin, Burkina Faso, in the Sudan savannah zone. Millet yield response to NPK fertilization and unfertilized intercrop treatments with cowpea and *P. aureus* at Yalka in 1987 is shown in Table 2. The same worker also observed, in 1988 at Kamsaoghin and Kamsi, a decline in grain yield of millet intercropped with a local cowpea cultivar as compared to its pure-stand crop treatment, which was consistent with reports by other workers (Muleba *et al* 1985; Sawadogo *et al.* 1985; Endondo 1997; Toky and Renaud 1997). He attributed the yield gain of millet intercropped with early cultivars of cowpea and *P. aureus* in 1987 as due to the release of N_2, biologically fixed, in the agro-ecosystem, prior to millet maturation, by the decaying root biomass of both grain legume crops.

Because pure-stand millet yielded more than twice less in 1987 (400-479 kg ha^{-1}) than in 1988 (1048 kg ha^{-1}) (Kibreab 1992), this may infer that factors other than low soil fertility might have limited millet yields in 1987. The high requirements of equivalent NPK (36.5N:10P:8.2K) fertilization of 212 kg and 234 kg ha^{-1} to achieve the yield of 712 kg and 744 kg ha^{1} for millet intercropped, respectively, with field bean and cowpea (Table 2) appears to support this hypothesis. Since 1987 was hotter and dryer than 1988 in Burkina Faso, it is also possible that the stimulation of microbial activities including VAM by legume plants might have improved nutrient and water uptakes of intercropped crop millet. This, in turn, might have given intercropped millet an advantage over its pure-stand counterpart.

5.2. Legume-cereal rotations

In West Africa, cowpea enriched soils with 20-25 kg N ha^{-1} (Nnadi 1978; Kang 1983). In Burkina Faso, sorghum yielded an average of 315 kg of grain ha^{-1} more when following cowpea than millet (Stoop and Van Staveren 1982). In Niger, the rotation of millet with cowpea or groundnut has boosted millet productivity and improved the N use efficiency at all tested locations (Bationo *et al.* 1997). Similar results were reported in northern Cameroon with sorghum rotated with either cowpea and groundnut or cotton, receiving NPK fertilization (Endondo 1997). In spite of its high "harvested N index" (HNI) and the manual harvesting by pulling up plants and transporting them to drying and threshing areas, without returning the residues to the fields for ploughing them under, a medium maturity soybean cultivar induced, in a subsequent maize crop fertilized with only 20 kg N ha^{-1}, a yield equivalent to a fertilization of 60 kg N ha^{-1} of a maize crop following maize (Carsky and Berner 1997).

The soil fertility improvement attributes of legume plants and their yield enhancement on subsequent cereals may be fully appreciated by examining a five years study, involving cereals rotated with either cereal or yam, or grain legume crops, conducted in northern Ghana from 1982 to 1986 (Tetebo *et al.* 1992). Only data showing unfertilized preceding crop treatments and the maize and the sorghum treatment fertilized with 60 kg N ha^{-1} in the maize and the sorghum experiment, respectively, are shown in Tables 3 and 4. The sorghum preceding crop treatment consistently reduced maize yields throughout the experimentation (Table 3). It thus contrasted with groundnut and yam preceding crop treatments. Both treatments consistently boosted maize yields. Groundnut was, however, the best maize preceding crop treatment. Its induced yield increase was equivalent to a fertilization of 44.1 kg N ha^{-1}, whereas that of yam was 16.1 kg N ha^{-1}. Maize/groundnut intercrop, as a preceding crop, was intermediate between yam and groundnut. In the sorghum experiment, none of the preceding crop treatments consistently boosted its yields (Table 4). One should, however, note that on a five years average, maize as a preceding crop induced the least sorghum yield increase; it was followed by yam. Whereas groundnut induced the highest yield increase and was followed by the maize/groundnut intercrop preceding crop treatment. The yield increases due to the latter two treatments corresponded to a fertilization of 70.4 kg and 51.5 kg ha^{-1}, respectively.

Rotating cereals with either yam or legumes was proven highly advantageous to cereals' productivity (Tetebo *et al.* 1992). Since yam is not a biological N_2-fixer, yield gains it induces on subsequent cereal crops may be due to its beneficial effect on soil microbial and faunal activities, at least, as far as subsequent cereal crops are concerned. It is possible that the cultivation of yam eliminates cereal crop residues in the growing media. This in turn prevents, in the growing media of the subsequent cereal crop, the generation of toxins and/or the accumulation of deleterious micro-organisms responsible of allelopathy to which cereals are susceptible (Cochran *et al.* 1977; Kaspar *et* al. 1990). Thus, cereal yields decline when following another cereal crop, particularly maize following sorghum, observed in SAWA even under field fertilization (Tetebo *et al.* 1992; Endondo 1997; Kombiok *et al.* 1997; Muleba 1999), could just be another demonstration of allelopathic effect of cereal crop residues in tropical fields. The work by Vivekanandan and Fixen (1991) illustrates also the importance of legume stimulated micro-biological activities, which, in the subsequent season, increase cereal outputs. These workers, showed maize following soybean was highly productive with roots densely colonized by VAM than when following barely. Legume crops are, therefore, highly instrumental, in enhancing the productivity of subsequent cereals, as they combine two attributes favourable to cereals, i.e., improvement of mineral nutrition, particularly N and P, and the mitigation of the effects of deleterious micro-organisms.

6. Use of legume plants in intensification and integration of crop and livestock production systems in SAWA

Maize crop, compared to sorghum and millet, responds very little to sparingly soluble natural rock phosphates Kodjari, Park W and Hahotoe from Burkina Faso, Niger and Togo, respectively (Bationo *et al.* 1988). Cowpea and *Crotalaria retusa*, as preceding crops fertilized with the Kodjari rock phosphate, induced a yield gain of 769 kg ha^{-1} and 773 kg ha^{-1}, respectively, in the subsequent maize crop in Burkina Faso (Muleba 1999). Endondo (1997) observed cowpea and *Crotalaria* were the best preceding crops for sorghum and maize in northern Cameroon. The two legume crops can, therefore, be used in combination with natural rock phosphates to replenish nutrient mined soils of the sub-region (Bationo *et al.* 1997) and so restore their soil fertility. Natural rock phosphates, in addition to P, supply also iron, calcium and other nutrients to soils (Muleba and Coulibaly 1999).

Several legume cover crops *Mucuna utilis, Callopagonium mucunoides, Pueraria phaseolides, Canavalia ensiformis, Maroptilium atropureum, Centrosema pubescens, Cajanus cajan, Stylosanthes hamata, Lablab purpureus,* and others are being studied for their soil conservation and fertility improvement attributes in SAWA. In Burkina Faso, crops such as *M. atropureum,* which cover rapidly the ground, also improve soil surface and sub-surface physical and chemical properties, including pH, OM, exchangeable K and C/N ratio; and increase yields of subsequent maize crops (IITA/SAFGRAD 1987). Similar results were observed in northern Cameroon with *Mucuna utilis* (Endondo 1997). This crop, however, contrasted with *Canavalia ensiformis* and *Cajanus cajan.* The former crop grew slowly, but provided good ground cover late in the growing season. Whereas the latter crop grew slowly and continued growing even during the early part of the dry season, but never provided a good ground cover (Endondo 1997).

When legume cover crops were intercropped with maize or sorghum, none of them depressed cereal yields (Endondo 1997). The yield declines of 4% and 9% observed for maize and sorghum, respectively, were statistically insignificant. The forage yields were 3 tons ha^{-1} for *C. mucunoides*, 4.3 tons ha^{-1} for *S. hamata*, 8.1 tons ha^{-1} for *C. ensiformis*, and 8.75 tons ha^{-1} for *C. cajan*. In November, *C. mucunoides* and *S. hamata* had already dried out, whereas *C. ensiformis* and *C. cajan* remained green (Endondo 1997).

Agricultural settlers can, thus, grow legume cover crops either as improved fallow, fertilized with natural rock phosphates, or as intercrops with cereals; harvest, dry and store them as hay. The hay so produced along with grain legumes haulms--cowpea or groundnut--can be fed to penned livestock as protein supplement. Yilala (1988) supplemented sorghum hay with cowpea hay and increased total feed intake of Bali Bali sheep in Burkina Faso from 1135 g/day, for the not supplemented diet, to 1350 and 1536 g/day, for the diets supplemented with 200 g and 400 g of cowpea hay, respectively. The rate of change in roughage intake was increased (+0.10) and reduced (-0.25) by, respectively, the 200 g and 400 g cowpea hay supplement. The annual dry matter faecal output was reduced from 153 kg/head/year (kg/hd/yr), for the not supplemented diet, to 152 and 140 kg/hd/yr, for the 200 g and 400 g supplemented diets, respectively. The N, P and K_2O were 2.1:0.23:1.2, 3.0:0.27:1.3, and 3.0:0.28:1.5 for the not supplemented, and the 200 and 400 g cowpea supplemented diets, respectively. With 20 sheep, one would fertilize 1 ha of cereal crop. But he or she will need a total of 11,750 kg of hay of which about 3,100 legume hay to feed them, which is not out of farmers' reach at this point in time in SAWA (see Endondo 1997).

7. Lessons and technical recommendations

The review of agricultural production systems, production technologies actually in use and those in the pipeline in SAWA enables us to draw some lessons and to formulate some technical recommendations as follows:

7.1. Lessons

1. People in SAWA heavily rely on cereal crops as major sources of food energy for their survival and normal productive life. As a consequence, farmers, in search of food security, give top priority to cereal crop production over other crops.

2. A combination of unfavourable factors, including: high demographic pressure, use of production technologies dating from the shifting cultivation epoch, unavailability and/or unaffordability of chemical fertilizers to farmers, insufficiency of organic fertilizers, and the intolerance of cereal crops to continuous cropping have compelled farmers to expand agricultural production into marginal lands and to curtail the fallow duration to less than 5 years or eliminating it altogether without achieving food security.

3. Instead, the *per capita* food production has been declining since mid-1970s. This has resulted in the Sub-Saharan Africa importing up to 12 million tons of food items in 1995. If new, appropriate production technologies are not extended to and adopted by farmers to boost cereal productivity, food imports in the sub-region are expected to reach 27 million tons in the year 2020.

4. Several appropriate technologies, validated by agricultural research systems, are now available in the sub-region. They include cereal-legume crop rotations and associations; use of cheap, native rock phosphates for soil fertilization in combination with legume crop cultivations; harvesting of hay, fodder and haulms from, respectively, forage legumes, native grasses and cereal and grain legume crops; storage of these forage for feeding penned livestock; and collection of animal manure for fertilization of cereals crops. They need to be extended to farmers for appreciation and finally adoption.

5. The thermodynamic law states that : "*no matter is destroyed, no matter is recreated; they only change from one state to another*". Similarly, "*there is no free lunch; you eat only what you pay for*". Therefore, if modern agricultural production in developed world is capital intensive; low input, sustainable agriculture in developing world, including SAWA, is knowledge intensive. Scientists in SAWA will have to work very hard, teach their respective farmers the usefulness of the new technologies, so they can adopt them, improve their productivity and production, and increase their incomes while conserving the vital soil resource base.

7.2. Recommendations

1. Since continuous cereal cropping is incompatible with a sustainable agriculture in SAWA, as it causes yield declines resulting from allelopathic effects of cereal crop residues, in the growing media, and from *Striga* parasitism, which infestation it promotes, this technology should be discouraged for use by farmers. Instead, it should be replaced by cereal-legume crop rotations or at least cereal-legume intercropping systems. The new technologies provide good ground cover and thereby combat the exposition of soils to excessive rainfall impact and solar radiation. They also enrich soils with biologically fixed N_2, and P and other nutrients mobilized from unavailable soil-pools, while riding soil of cereal unfavourable effects of deleterious micro-organisms and *Striga.*

2. The current soil nutrient mining in the sub-region can be halted, soil fertility restored, and soil resource base rebuild by combining the incorporation of legume plants, fertilized with natural rock phosphates, in rotations with cereals in cropping systems. While biologically fixing N_2, legume plants through symbiosis with VAM micro-organisms would mobilize less soluble nutrients such as P, Fe, Ca and other, brought by these fertilizers, and make them available to subsequent cereal crops.

3. To take full advantage of the introduction of legume plants in the cropping systems, farmers should be thought to pen their livestock; harvest legume and grass hay, cereal fodder and grain legume haulms; store and feed them rationally to livestock. They will have to collect livestock manure and fertilize cereal crops. The new production technologies if properly extended to and adopted by farmers are highly conducive to improved cereal and livestock productivity. They will contribute also to farmers achieving food security, increasing incomes while conserving soil resource base.

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