Sustainable agriculture in the West African savannah: considerations for modern crop promotion in traditional farming systems

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Abstract

Sustainable agriculture techniques in West Africa are largely based on the planting of modern crop varieties of nitrogen-fixing legumes to improve soil fertility and increase harvest yields for the subsistence or smallholder farmer. In the northern savannah of Togo, native crop varieties, or landraces, of intercropped sorghum and cowpea were grown in a demonstration field for comparison with internationally promoted monocropped soybean and the cover crop mucuna. After two growing seasons, no significant changes in soil chemistry were observed. However, harvested yields of the native crops were double those of the promoted modern crops. Several biological and practical reasons account for the failure of soybeans or mucuna to improve soil fertility over the two-year period. Similarly, the genetic and cultural benefits of traditionally intercropped sorghum and cowpea may further hinder local farmer adoption of soybean or mucuna. These observations suggest that the widespread promotion of soybean and mucuna to improve soil fertility may not be appropriate within the context of specific environmental conditions and cultural practices. Sustainable agriculture initiatives might be better achieved if based on increased research of native crops, trees and forages for use within tailored ‘in situ’ soil conservation projects that incorporate indigenous farmer knowledge and local cultural values. For this aim, appropriate sustainable agriculture projects require adaptive interdisciplinary approaches that integrate farmer participation with both socioeconomic and biophysical research.

Keywords: soil fertility, harvest yield, landraces, West Africa, nitrogen fixation, cover crops, indigenous knowledge, sustainable agriculture.
1 Introduction

Farming practices in West Africa are historically based on shifting cultivation to maintain soil fertility. In the past, when land was abundant, traditional slash and burn systems allowed farmers to cultivate land for two to five years and then abandon it for up to 10, sometimes 25, years for fallow before cultivating again [1]. However, rapid increases in human and livestock populations no longer allow such long fallow cycles; marginal lands have been brought into cultivation, and farmers have been forced to change from extensive to intensive cultivation of the land [2, 3]. This intensification of cultivation has contributed to widespread deforestation and desertification, soil acidification, invasion by noxious weeds, and a marked decline in soil fertility and harvest yields [3, 4]. At present, only 24% of West African soils are fertile enough to support crops, while the remaining 76% are characterized as poor with severe deficiencies in nitrogen and/or phosphorus, requiring the liberal use of fertilizers, organic-matter management, and erosion control [4]. With increased population growth and the agriculture sector currently responsible for one-third of the continent’s gross domestic products, agricultural development in Africa to sustain and improve food, animal feed, fuel wood and fiber productivity, is as critical to economic growth as it is to the continent’s food security and to population health.

According to the Food and Agricultural Organization, approximately 70% of the African population lives in rural areas as subsistence or smallholder farmers. Accordingly, development organizations, government agencies and research institutions currently working in West Africa to improve agricultural productivity are largely focused on sustainable agriculture technologies for the individual smallholder or household farmer. As most rural African farmers cannot afford the purchase of inorganic fertilizers, the majority of these technologies are based on the use of organic amendments and biological nitrogen fixation as a means to improve soil fertility and increase harvest yields [2, 5, 6]. Although the nutrient benefits of the lost fallow system are not easily replaced by changes in soil tillage or cropping practices [7], current soil improvement technologies represent "low-tech" but knowledge intensive practices and include agroforestry systems and alley cropping with leguminous trees; crop and shrub residue mulching; and the planting of non-traditional or introduced "modern" leguminous and green manure crops [2, 3]. In Togo and in many other parts of West Africa, soybeans (Glycine max), and the cover crop mucuna (Mucuna pruriens), are often promoted for rotation with, or as companion crops to, the traditional sorghum/cowpea (Sorghum bicolor and Vigna unguiculata) intercrop to improve soil fertility and augment harvest yields, as well as to provide supplemental nutritional choices and income-generating activities.

A native crop of Asia, soybeans were introduced in Nigeria roughly 20 years ago, but were not actively promoted until 1987 when the International Institute for Tropical Agriculture (IITA) launched an ambitious effort to combat widespread malnutrition. According to the IITA, soybeans have an average protein content of 40%, which is more than any other common vegetable or animal food source found in Africa. Since 1987, over 150 different soy food
products have been developed in Nigeria, which now produces over 500,000 tons of soybeans worth $85 million annually for use in more than 65 soybean-processing industries [8]. The large-scale adoption of soybeans in Nigeria as a successful cash crop and protein source, in addition to its nitrogen-fixing capabilities, has led to its promotion by national governments and development agencies in other West African countries such as Togo for incorporation into malnutrition and soil fertility initiatives. Eaglesham and Ayanaba [9] estimated that soybean rotations in Nigeria contribute anywhere from 15 to 125 kg/ha of residual soil nitrate while native cowpeas contribute an average of 122 kg/ha [2]. In South Africa, Bloem [10] found that maize yields increased by 27% and 51% after rotation with cowpea and soybean respectively and suggested that soybeans may also contribute to beneficial soil microbial activity or excrete growth-promoting substances.

The origins of the leguminous cover crop mucuna or velvet bean are not well-known, although it is thought to be indigenous to Asia or Central America. Mucuna for cultivation was first introduced to West Africa in the late 1980’s by the National Institute of Agricultural Research in Cotonou, Benin, and later by other national and international extension services. As a nitrogen-fixing legume, mucuna has been widely promoted as a green manure cover crop to improve soil fertility, suppress weeds and control erosion [11, 12, 13]. Although mucuna has also been shown to increase soil porosity and infiltration rates [14], the main nutrient advantage in mucuna is from the mineralization of crop biomass. Mucuna grown in humid regions can provide as much as 12 ton/ha in aboveground dry matter biomass [12] and can contribute as much as 100 kg/ha of nitrogen to the following crop [15]. In field tests in Benin, maize crops following one-year mucuna fallows resulted in increased seed yields of approximately 500 kg/ha for local maize varieties and 800 kg/ha for improved varieties [13, 16]. Several different varieties of mucuna are distributed by development and extension agencies in Togo to farmers for use as a sole cover crop planted as a short fallow for severely degraded soils, or as a sorghum or maize intercrop for fields requiring less rehabilitation.

2 Case Study: Tamberma Valley, northern Togo

The Tamberma Valley is located in the north eastern Kara region of Togo. With less than 1000mm of annual rainfall and 180 days in the growing season, the area is considered a tree and shrub savannah within the Sudano-Guinean ecological zone. The Tamberma people are both geographically and culturally isolated from the other 40 different ethnic groups in Togo, and as a result, have retained much of their traditional cultural and farming practices. In general, the Tamberma are subsistence farmers that practice a diversified system of agricultural production based on non-irrigated crop rotation, with some fallow seasons if resources permit, combined with the raising of a variety of livestock. The traditional staple crops are millet, sorghum, cowpeas, groundnuts, chickpeas, and fonio (Digitaria exilis). As is typical of most West African farming systems in semi-arid zones, sorghum and millet in Tamberma Valley are almost exclusively intercropped
with cowpea. The Tamberma people are thought to have migrated to northern Togo and Benin from the Fada-N’Gourma region of Burkina Faso approximately 500 years ago, suggesting that growing conditions at this time may have been more favourable. According to oral accounts and limited rainfall data, this region had more forested land and a longer growing season in the recent past. However, deforestation, annual bush fires, and increasingly intensive cultivation combined with a growing population have contributed to soil degradation and less opportunity for fallow seasons. The alfisols of the Tamberma Valley are currently among the poorest and most highly degraded soils in Togo [17], primarily due to low fertility and severe wind and water erosion [18].

For these reasons, a soil improvement demonstration field was established in the Tamberma village of Warengo under the direction of local and international development organizations and regional government agencies. The objective of the 1600m² demonstration field was to introduce local farmers to soybean and mucuna rotation and compare them to the traditional sorghum and cowpea intercrop through direct observation and participation. Using a standard spacing of 0.25m between all plants, local sorghum seed was intercropped with local cowpea seed the first year in two plots in the southern half of the field, while modern varieties of soybean and mucuna were separately monocropped in two plots on the northern half of the field. Using the same spacing, the plots were rotated the second year in order to follow the local tradition of annual crop rotation, as well as to observe any increase in subsequent sorghum seed yield as a result of previous soybean or mucuna cultivation. Seed yield data for each crop was collected after each year's harvest. Composite topsoil samples were taken at 10cm below the soil surface from 10 randomly selected sites within each of the four planted plots as well as from the surrounding natural Andropodon grass fallow. Soil samples were taken at the beginning of each planting season (June 2000 and 2001), the end of each harvest (November 2000 and 2001), and once during the dry season (March 2001). The soil samples were sieved to the 2mm fraction and analyzed at the National Institute for Agronomic Research (ITRA) in Lomé, Togo. ITRA used flame photometry and atomic absorption spectrometry to determine soil sodium, potassium, calcium and magnesium, colorimetry using the Olsen method for available phosphorus, spectro-photocolorimetry using potassium dichromate and sulphuric acid for carbon and organic matter, and titration using the Kjeldahl method for nitrogen.

The results for harvest yield (Table 1) show a large difference between the traditional intercropped cowpea/sorghum and the monocropped soybean and mucuna. As cowpea and sorghum are intercropped as companion crops on the same area of land, their net harvests must be added together to provide a total of 1213 kg/ha of seed for the year 2000 harvest and 1143 kg/ha of seed for the year 2001 harvest. Thus, the total yield of food per unit of land for monocropped soybean and mucuna was less than half of what was harvested for the traditional sorghum/cowpea intercrop. Additionally, soil nutrient measurements across all plots did not show any significant changes in soil nutrients over the two-year period (Table 2). Even though the demonstration plots were not successfully replicated for further statistical analysis, the attempt to demonstrate to farmers
the effects of soybean and mucuna rotation on soil fertility and harvest yield was not successful over the two-year study period. With this experience, several potential biological and practical explanations arose as "lessons learned" for subsequent project development.

### Table 1: Harvest yield.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (ha)</th>
<th>Harvest (kg)</th>
<th>Net (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 2000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cowpea</td>
<td>0.104</td>
<td>66</td>
<td>635</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.104</td>
<td>60</td>
<td>578</td>
</tr>
<tr>
<td>Soybean</td>
<td>0.035</td>
<td>21</td>
<td>605</td>
</tr>
<tr>
<td>Mucuna</td>
<td>0.025</td>
<td>15</td>
<td>595</td>
</tr>
<tr>
<td>Year 2001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cowpea</td>
<td>0.094</td>
<td>60</td>
<td>635</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.094</td>
<td>48</td>
<td>508</td>
</tr>
<tr>
<td>Soybean</td>
<td>0.045</td>
<td>24</td>
<td>532</td>
</tr>
<tr>
<td>Mucuna</td>
<td>0.026</td>
<td>15</td>
<td>564</td>
</tr>
</tbody>
</table>

### Table 2: Measured soil chemistry averages.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean</th>
<th>n</th>
<th>s.d.</th>
<th>Measurement</th>
<th>Mean</th>
<th>n</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>% OM</td>
<td>4.32</td>
<td>25</td>
<td>1.04</td>
<td>Ca (cmol/kg)</td>
<td>6.69</td>
<td>20</td>
<td>3.9</td>
</tr>
<tr>
<td>% C</td>
<td>2.52</td>
<td>25</td>
<td>0.59</td>
<td>Mg (cmol/kg)</td>
<td>1.3</td>
<td>20</td>
<td>0.35</td>
</tr>
<tr>
<td>% N</td>
<td>0.14</td>
<td>25</td>
<td>0.02</td>
<td>K (cmol/kg)</td>
<td>0.272</td>
<td>25</td>
<td>0.15</td>
</tr>
<tr>
<td>C/N Ratio</td>
<td>16.99</td>
<td>25</td>
<td>3.62</td>
<td>Na (cmol/kg)</td>
<td>0.071</td>
<td>25</td>
<td>0.09</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>19.01</td>
<td>25</td>
<td>5.92</td>
<td>pH (H₂O)</td>
<td>6.16</td>
<td>25</td>
<td>0.23</td>
</tr>
</tbody>
</table>

3 Biological constraints

In the low fertility soils of the West African arid zones, there is an inherent limitation of leguminous crops to produce sufficient biomass to significantly alter soil fertility characteristics over a two-year study period. The maximum potential nitrogen contribution can be calculated using aboveground dry matter averages for the crops in the semi-arid savannah zone and their corresponding inorganic nitrogen content discussed in previous studies. Using this method, the cowpea crop is estimated to have produced 2.5 t/ha of dry matter [12], not including harvested seeds, and with an average of 10 kg nitrate N per t/ha biomass [10], therefore could have potentially contributed 25 kg/ha of nitrate nitrogen to the field. Soybeans can potentially contribute 10 kg nitrate N per t/ha of soybean seed yield [10]. Based on the 2-year average soybean seed yield of 0.568 t/ha, the soybean crop is estimated to have contributed 5.7 kg/ha of nitrate N. Finally, the mucuna crop is estimated to have produced 4.7 t/ha of aboveground biomass, including unharvested seed [12], and with approximately 10.7 g of inorganic N per kg of aboveground biomass [19], could potentially have contributed 50 kg/ha of inorganic N. Thus, the maximum contribution of inorganic nitrogen from the combined aboveground biomass of cowpea, soybean
and mucuna in the demonstration field was estimated to be approximately 81 kg N/ha. Using the standard average of 2.2 million kg of soil per hectare, the average nitrogen content of 0.14% found in this study of Tamberma soils represents 3080 kg of total nitrogen per hectare. The maximum potential inorganic nitrogen contribution of 81 kg/ha from the calculated and combined aboveground biomass production of cowpea, soybeans, and mucuna represents only 2.6% of the present total nitrogen content and would therefore only provide a very small (0.003%) overall increase in soil nitrogen content. As a result, this potential maximum contribution of 0.003% annual increase in nitrogen content is too small to be recognized within the less than 0.1% variation in soil nitrogen content measured over the two-year study period.

Low fertility soils can not only limit initial biomass production, but can also affect other physiological processes that influence biomass nutrient content and nitrogen fixing capabilities. Research in Benin by Houngnandan [20] showed that mucuna biomass nutrient composition decreased by 69% for nitrogen and 33% for phosphorus when these nutrients were absent from the growing medium. The capacity for root nodulation and nitrogen-fixation capability is also inherently limited by soil phosphorus content for soybean [21], and soil nitrogen for mucuna [22, 23]. Specific rhizobial populations must also be present in the soil to promote nodulation. As introduced crops, native rhizobial bacteria populations necessary for root nodulation of mucuna and soybean are generally lower or nonexistent in West African soils [20, 22]. Thus, without improved varieties, a stable supply of inoculant, or other soil nutrient amendments, the soil nitrogen contribution from mucuna and soybean in this region would be expected to be lower than that for the native cowpea.

4 Practical constraints

The IITA in Nigeria has developed improved varieties of soybean that fix more nitrogen without rhizobial inoculation and have lower phosphorus requirements. However, the problem remains as to how to maintain a consistent supply of these improved varieties to farmers. In Togo, soybeans for cultivation are bought in local markets, including many of those distributed by development organizations, without knowledge of where the seeds came from or how far removed they are from the original variety. Even if select farmers were given an original strain, the widespread practice of saving out harvested seed for the next year’s planting would quickly lead to hybridization. By contrast, mucuna seeds are not currently found in local markets in Togo, but are mainly distributed by local and international non-profit organizations and agricultural development agencies. As a result, farmers’ exposure to mucuna varieties depends entirely on consistent access to a mucuna promoting organization in the area.

The effect of the long dry season in the West African savannah and sahel regions cannot be underestimated. Nutrient rich biomass to be incorporated back into the soil for the benefit of the next growing season must be protected during the dry season from post-harvest bushfires, free-range grazing animals and erosion from the scouring Harmattan winds. In coastal areas with bimodal
rainfall and longer growing seasons, soybean and mucuna are promoted as companion or intercrops to maize, millet or sorghum. Like the cowpea in sorghum intercropping, intercropped soybean or mucuna must be planted 30 to 45 days after the cereal crop in order to prevent initial crop competition for nutrients. However, due to lower rainfall conditions, a shorter growing season, slower growth, and nutrient competition, soybean and mucuna can generally only be planted as monocrops in semi-arid savannah. Monocropping can be very labour intensive and is often an inefficient use of land. For example, cowpea intercropped with sorghum, grows to cover the spaces between sorghum plants and therefore, requires little weeding. As a cover crop, mucuna also requires little weeding during the growing season, however, incorporation of crop residues at the end of the harvest is often extremely difficult in the already dry soils. With their more shrub-like growth, soybeans are more labour intensive as they often require multiple weedicings per growing season.

5 Compatibility with indigenous knowledge and practices

Hundreds of years of accumulated knowledge and experience provide farmers with a variety of details and improved methods for native seed selection, storage, and crop harvesting, planting and weeding. For example, Tamberma farmers can identify and select for market or for sowing different sorghum and cowpea varieties by their color, taste, size, hardness and plant growth characteristics. With newly introduced modern crops, farmers do not have this advantage of time-tested knowledge. Similarly, little local knowledge exists for the integration of soybean and mucuna into traditional farming systems. No local knowledge exists for selecting the type of land, such as lowland, riparian, or hillside sites, as well as proximity to specific animal predators, which will best accommodate soybean or mucuna cultivation. Farmers have no experience with identifying soybean or mucuna crop diseases or signs of nutrient deficiencies. Additionally, farmers do not have the experience or precedence necessary to place soybean or mucuna into their crop rotation or intercropping systems. Instead they must rely on outside organizations for information, which for an illiterate population, can only be successfully retained by numerous trainings and actual hands-on experience.

Mucuna in general is not a readily accepted food crop due to unfamiliarity with preparation and cooking requirements necessary to remove the high levels of L-Dopa toxin. In light of a growing population, decreasing fallow opportunities and smaller household farms, most subsistence farmers may not be able to risk cultivating a portion of their land with an unfamiliar crop without the benefit of income-generation or an edible seed harvest. As a recognizable food crop with commercial value [8], soybeans have been more accepted than mucuna for cultivation. However, an underlying problem with soybean adoption in more isolated regions such as in the Tamberma Valley is related to strict gender roles in the community, which are common to many societies in West Africa. In the Tamberma Valley, women cultivate the bean crops, while men cultivate the cereals. As a result, soybeans are generally only promoted to women and remain
an unfamiliar and unimportant crop to men, which can create difficulties for women in obtaining household land for soybean cultivation.

As traditional crops, cowpeas and sorghum also have important cultural and economic roles. In the Tamberma Valley, bean cakes made from cowpeas are used in important rain ceremonies and coming-of-age initiations while the preparation of sorghum-beer is the main income-generating activity for many West African women. Dry sorghum stalks are cut in half at the end of the harvest for use as fuelwood and for construction of doors and animal pens, while the remaining lower half of the stalks are left standing in fields to camouflage household chickens and guinea fowl from hawks and other bird predators. It is nearly impossible for newly introduced modern crops such as soybean and mucuna to fill the numerous integrated cultural and practical roles of native crops in traditional farming systems.

6 Inherent benefits of the cowpea/sorghum intercrop

From a production perspective, the main value of native crop varieties appears to be their contribution to genetic diversity and their adaptation to local growing conditions [24, 25]. Modern crop varieties are generally introduced and developed to provide relatively high yields under optimal growing conditions for a broad geographic region. In marginal environments such as the semi-arid savannah zones, varieties of modern crops such as soybean or mucuna often need relatively high levels of inputs in order to reach the optimum yields and benefits for which they are promoted [24]. Genetically adapted native crop varieties are less sensitive to minor fluctuations in local environmental conditions, resulting in more consistent and sustainable harvest yields over time, which is often more important to subsistence farmers than the promise of simply higher yields. Native crop varieties may have lower mean yields in optimal environments compared with other varieties, but often have higher mean yields in the marginal environments to which they are adapted [24]. For example, the cowpea varieties grown in Tamberma Valley may represent the result of numerous genetic adaptations to the local conditions, as the approximately 600 kg/ha average cowpea yield in this area is well above the 300 kg/ha average cowpea yield reported for all of Africa [8].

The majority of cultivated area in West Africa is under a mixed cereal/legume cropping system, yet there has been relatively little biological or genetic research on these intercropped systems. In low nutrient soils, cowpea roots may excrete nitrogen for the benefit of the companion crop [26]. Cowpeas have also been shown to increase pH and available phosphorus in the rhizoplane [27]. Aboveground cowpea litter or dry matter, soluble leaf nitrogen and nitrogen from decaying root nodules may also account for the nitrogen transferred to the cereal [28]. Intercropping legumes and cereals also is beneficial because it reduces the risk of total crop failure from selective pathogens, makes efficient use of land and labour, and provides farmers with a balanced diet. Cowpea grown with sorghum can also be a sound soil-conservation strategy as it provides
a complementary ground cover that reduces weeding and soil erosion, while maintaining soil moisture.

7 Conclusions

Selected farmers in West Africa have indeed benefited from the cultivation of recently introduced modern crops. In parts of Nigeria, soybeans have already developed an economic niche and are quickly becoming an important cash crop, providing a much needed income to families. As a green manure crop, mucuna has helped some farmers in the more humid regions of Benin, Togo and Ghana to recover fields previously abandoned to weeds and to increase maize yields. These successes, however, are not only dependent on consistent farmer access to development organizations for seed, inoculant, and knowledge, but also on specific environmental and cultural conditions necessary for optimal soybean or mucuna growth and subsequent soil enhancement. The farther traditional farming systems are from these optimal environmental and cultural conditions required for modern crop varieties to succeed, the more sustainable agriculture projects need to rely on the existing adaptations and benefits of native crop varieties to address soil fertility problems.

The promotion of modern crop varieties that overlooks the specific cultural, economic, and practical roles of native crops and traditional farming systems, increases the risk of losing traditional knowledge and local crop genetic diversity. To more appropriately match sustainable agriculture technologies to local farming systems, sustainable agriculture projects might be better developed initially "in situ," relying on local resources and emphasizing the preservation of native seed genetic diversity, farmer knowledge and crop stability. "In situ" research and development projects would require an increased understanding of the local farming system and more research on the available native crops, forages and tree species for use within a specific environmental and cultural context. These integrated projects would rely on a combination of socioeconomic and biophysical research integrated with local farmer participation. For this to be achieved, interdisciplinary and interagency collaboration is essential.

Many development organizations and research institutions are already using more participatory techniques to create and implement "in-situ" soil improvement and sustainable agriculture projects. These participatory research approaches give greater attention to local farming practices, farmer needs and farmer knowledge by involving local community members in each of the diagnostic, design, implementation and evaluation phases of a development project [29]. The challenge remains as to how to integrate identified local knowledge and farmer priorities with scientific knowledge and interdisciplinary research activities. Researchers and development agencies need adaptive interdisciplinary tools to strengthen communication and understanding between disciplines, institutions and project beneficiaries. For this aim, development organizations, research institutions and government agencies are encouraged to share resources and seek more opportunities for collaborative partnerships and interdisciplinary research.
References


