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Cowpea as a key factor for a new approach to integrated crop–livestock systems research in the dry savannas of West Africa

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Abstract

Agriculture in the dry savannas is intensifying in response to increasing populations of humans and livestock. As a result, increased productivity demands are placed upon integrated crop–livestock systems and more emphasis is on the roles of legumes such as cowpea. Cowpea has the potential to function as a key integrating factor in intensifying systems through supplying protein in the human diet, and fodder for livestock, and bringing nitrogen into the farming system through nitrogen fixation. This paper describes the development and evaluation of integrated "best-bet" options which maximize the benefits of cowpea and addresses aspects of improved crop varieties, crop and livestock management, nutrient cycling, and soil fertility. The approach used includes a multicenter, multidisciplinary approach to working with farmers which combines complementary strengths of previous component research involving crops and livestock by key international and national research institutions in the region.

Introduction

Cowpea is an important crop for farmers in much of the West African region, particularly in the dry savannas. Estimates of world hectarage of cowpea is in the range of 12.5 million, with about 8 million in West Africa, the majority of these being in Niger and Nigeria (Singh et al. 1997). Current FAO estimates for 1999 are lower than these figures, although the proportions are similar (FAO 2000). The same database estimates average cowpea grain production in West Africa as 358 kg/ha whereas Singh et al. (1997) estimate 240 kg/ha as an average for northern Nigeria. The apparent popularity of the crop may seem paradoxical if only the relatively low grain yields on farmers' fields are considered. Perhaps this is related to the fact that cowpea is a legume with the potential for multiple contributions not only to household food production, but also as a cash crop (grain and fodder), livestock feed, and soil ameliorant. In this context, it is a crop that may have a wide role

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in contributing to food security, income generation, and the maintenance of the environment for millions of small-scale farmers who grow it in the region. In order to place such contributions in context, this paper will begin by considering the ongoing evolution of farming systems in West Africa, especially the integration of crop and livestock production, with reference to the particular features of the dry savannas where these scenarios are prominent. The potential role that cowpea can play in addressing the opportunities posed will also be addressed and as part of this, ongoing research which includes the utilization of such multiple benefits of cowpea will be considered.

The changing face of agriculture

In sub-Saharan Africa, the population may reach 1.2 billion by 2025 and be combined with a demographic shift from about 30% of the population (in 1990) in urban areas to at least 50% (Winrock 1992). These changes will mean an increasing demand for crops and livestock and even if production expands at the rate of 3% annually, which would be necessary to meet this demand (Winrock 1992), it is likely that at least 21% of the children, about 39 million, will remain undernourished (Badiane and Delgado 1995). Recent studies have indicated that through both natural accretion and the change in requirements related to urbanization (Ehui et al. 1998), livestock demand in particular is likely to increase dramatically, ranging between an increase of 2.5% for mutton, pork, and poultry, to 4.2% for beef between 1993 and 2020 (Delgado et al. 1999).

Within sub-Saharan Africa, more than 40% of the region's current population is in West Africa (based on FAO estimates for 1999; FAO 2000) meaning that the opportunities and challenges presented by the intensification scenario will be heightened in this region. One of the responses of farming systems to agricultural intensification is the integration of crop and livestock production (McIntire et al. 1992). As crop farmers seek to increase production, their cropping activities spread onto marginal land, fallow periods become reduced or absent, and consequently, the demand for nutrient inputs is raised. In the absence of reliable and cheap supplies of inorganic fertilizers, manure from transhumant livestock becomes more important. At the same time, as livestock keepers enlarge their herds, crop residues from crop farmers increasingly become the major feed resource because there is no longer marginal or fallow land for grazing. Estimates have shown that ignoring crop residues as a feed resource would result in serious feed shortages (Naazie and Smith 1997). In these scenarios, crop farmers may begin to own their own livestock for ready access to manure and simultaneously sell off some of the marginal land to livestock keepers, who settle and begin crop farming, using the manure from their animals (and possibly traction) as an input (Okike et al. 2001). In the dry savannas of West and Central Africa, crop–livestock integration is already a common feature of the farming systems.

Dry savannas

The dry savannas consist of the drier part of the northern Guinea savanna, plus the Sudan savanna representing more than 50% of the total land area of sub-Saharan Africa, with a significant proportion located in West Africa. Over 40% of the total ruminant livestock in West and Central Africa are in this region (Winrock 1992). Annual rainfall is less than 1000 mm with a growing period of 180 days or less meaning that much of the region experiences a long (7–9 months) harsh dry season. The growing period shortens on a south–north axis. The sandy soils are generally poor, with low organic carbon, and cation exchange capacity, and are deficient in nutrients, especially nitrogen and phosphorus.

Cropping is cereal-based with sorghum and millet dominating, and the former decreasing in prominence towards the north. Intercropping cereals with grain legumes is common in over 90% of fields, with cowpea and groundnut being the most common legume components. As well as grain, the residues from cropping, especially from cowpea (and groundnut), are important components of the farming systems in particular as fodder resources for the ruminant livestock which are also an integral part of the farming systems. Cattle, sheep, goats, and to a lesser extent camels, provide milk, meat, traction, manure, and cash.

Major constraints to agricultural productivity in the region include the long dry season, which results in crop stress due to drought at the beginning and/or end of the wet season and a shortage of ruminant fodder during the harsh dry period. The poor soils and incidences of pests and diseases also have negative effects on crop production (both grain and fodder). In much of sub-Saharan Africa, inputs such as fertilizers and pesticides to counteract these negative forces are generally scarce or priced well above the means of the smallholder farmer.

Farm sizes in the region are generally small, ranging from about 3 to 6 ha; each field is usually 1 ha or less and one farmer rarely owns contiguous fields (Ogungbile et al. 1999). A typical cropping pattern is as follows (Singh and Tarawali 1997). At the onset of the rainy season, cereal (millet or sorghum) is sown in rows with wide interrow spaces; two–three weeks later, a grain type of cowpea (short duration) is sown in alternate interrow spaces, followed by a fodder (or dual-purpose, late maturing) type of cowpea in the remaining interrows about three weeks later (Fig. 1). The cropping layout may be complicated by replacing some of the cowpea rows with groundnut and the timing of planting (but not the order) may vary, with the interval between planting the crops often much shorter than three weeks. Cereals will mature and be harvested first, together with the grain type cowpea, which will give a reasonable grain yield, but virtually no crop residue. The remaining dual-purpose/fodder type cowpea is left to grow over the rest of the field, until the rains cease and the leaves begin to show signs of wilting. At this stage, any grain on the plants is harvested, and the residue is cut and rolled up for storage on house roofs or in tree forks. The stored residue is fed to ruminants during the dry season, or, in some cases, sold in local markets where the high price during this period of feed scarcity means it will make a substantial contribution to a farmer's income. The cereal stalks remaining after harvest are fed to ruminants, but often, the leaves may be stripped off and fed to animals and

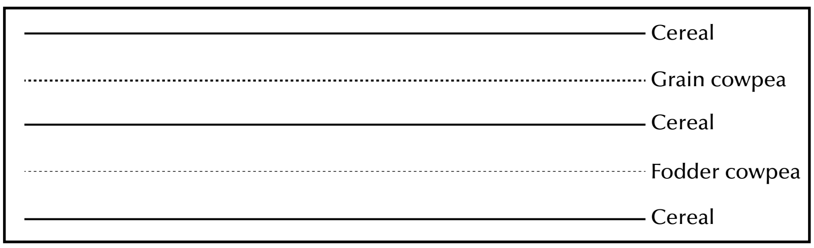

Figure 1. Schematic representation of common cropping pattern in the dry savannas. Spacing between the cereal rows can be as much as 3 m.

the stalks used as building or fencing materials. Ruminants within farm compounds are supplemented with the cowpea residues and, within the compound, the manure is collected with household waste. At the start of the next cropping season, the “compost” of manure and household waste is spread on the crop fields, before land preparation.

Thus, in the dry savannas, crop and livestock enterprises are closely integrated, with reciprocal benefits from crop residues as livestock fodder, and the latter providing manure and in some cases, traction, that contribute directly to crop production. While the benefits of such integration are recognized, and mixed crop–livestock farming systems, which currently contribute over 50% of the world’s meat and over 90% of its milk (ILRI 2000) are recognized to have the greatest potential for intensification (de Haan et al. 1997), food demands of expanding populations place increased pressure on these systems to raise productivity. Such productivity increases, if they are to be sustainable, need to be achieved without damaging the natural resource base. In some cases, where production of mixed farming systems has intensified, the full implications have not been considered as, for example, soil is mined and severely degraded and livestock waste products become a problem, etc. (Delgado et al. 1999). In this context, the situation in the dry savannas of West Africa, where integrated crop and livestock production systems have existed for many decades, but now face the pressure to produce more, is ripe for interventions that address these opportunities. Cowpea, which can contribute both to crop–livestock production systems, and directly to soil fertility, has the potential to make major contributions in this respect.

Contributions of cowpea towards increased and sustainable productivity in mixed systems

As a legume, cowpea can contribute to soil fertility, mainly through its nitrogen fixing abilities. Part of the nitrogen fixed will remain in the soil in the roots, and thereby contribute to the soil fertility for subsequent crops. Some fixed nitrogen will eventually return to the soil as manure after residues are fed to livestock. In terms of the direct effects of cowpea in rotation with cereals, Manu et al. (1994) report a comparison of on-station and on-farm studies in Niger where cowpea–millet intercrop and cowpea–millet rotations were used. Their results are summarized in Table 1. On farmers’ fields, rotation with cowpea gave 2.6 times more millet grain and 3.3 times more residue, than the intercropped, nonrotated treatment. Bagayoko et al. (1998) reported that cowpea can supply 35–40 kg N/ha in a cowpea–millet rotation, and Carsky and Berner (1995) presented similar figures for cowpea rotations with maize. See also Carsky et al. this volume.

Table 1. Summary of results comparing cowpea intercropping with rotation in farmer- and researcher-managed fields.

Cropping system		Yield (kg/ha) Farmer-managed	Researcher-managed
Traditional intercropping	Millet grain	62	172
	Millet residue	162	827
Rotation	Millet grain	163	308
	Millet residue	538	1531

Source: Extracted from Manu et al. (1994).

There is some evidence that cowpea may help to reduce the number of viable *Striga hermonthica* seeds in the soil through stimulating suicidal germination of the seed. *S. hermonthica* is parasitic on cereal plants, and causes huge crop losses (Berner et al. 1996). Carsky and Berner (1995) report that rotation with selected cowpea varieties has a substantial and rapid effect on reducing *S. hermonthica*, with the number of attached *S. hermonthica* plants per maize plant being reduced by at least 50% when maize was grown after cowpea.

Farmers' awareness of these roles of cowpea for soil fertility and *S. hermonthica* reduction is, to some extent, demonstrated by the fact that they usually rotate the legume and cereal rows within fields in alternate years. This means that the cereal and cowpea rows are interchanged each year, and the cereal will benefit at this "microlevel" from the cowpea grown in the previous year.

Cowpea residue is an important fodder resource for ruminant livestock (Tarawali et al. 1997). Farmers in the dry savannas deliberately grow varieties and use management practices that will ensure some cowpea fodder is available for harvest at the end of the growing season, even at the expense of grain production. Harvesting at the end of the wet season, before the dry season becomes severe, gives the best quality, and this is preserved throughout the storage period. If the fodder is harvested late, when the dry season is already underway, quality is poor (Tarawali et al. 1997). Recognition of the importance of fodder from cowpea led to the initiation of joint IITA–ILRI research in 1990 when fodder quantity and quality parameters were included in the breeding and selection program. These efforts resulted in the identification of promising dual-purpose cowpea varieties suitable for the dry savannas (Singh and Tarawali 1997).

Cowpea fodder as a feed supplement increases animal liveweight gain during the dry season. Schlecht et al. (1995) report an experiment where Zebu cattle (bulls of about 250 kg, equivalent to 1 TLU–Tropical Livestock Unit) were supplemented with 1 kg cowpea hay at night and 0.5 kg fresh rice feed meal in the morning per day/animal during the second half of the dry season. The animals were allowed to graze as usual for the rest of the day. From February 1988 to September 1989 the supplemented group gained 95 kg compared to 62 kg for the unsupplemented group. Taking animal numbers into account, this worked out to be equivalent to a difference of 67 g/animal/day. In many regions, cowpea fodder is particularly valued as a supplement in the period leading up to Muslim festivals when sheep are traditionally slaughtered. Some farmers sell cowpea fodder during the dry season when feed shortage is critical, and there have been suggestions that income from fodder sales makes a substantial contribution to the annual income in such cases (ICRISAT 1991). In addition to the direct benefits of improved livestock production and health that result from feeding cowpea fodder, the quantity and quality of manure from such better fed animals will be improved and therefore, when returned to the land at the beginning of the growing season, contribute more towards the maintenance of soil fertility. In the same experiment referred to above, although not significant in this particular trial, the manure nitrogen, in g N/TLU/day was on average 25% higher in animals receiving supplements.

Indications are that from 1 ha of improved cowpea, a farmer could benefit by an extra 50 kg meat per annum from better nourished animals, with over 300 kg more cereal grain as a result of improved soil fertility directly from the cowpea and more/better manure from the animals (Tarawali, unpublished). Of course, considerations of the time scale—increased crop yields—would be realized only the next year and the distribution of manure should be taken into account. It is, however, noteworthy that these preliminary calculations have not considered all the potential benefits, for example, better fed traction animals would work harder, meaning more timely land preparation and better crop yields; better fed ruminants would give more milk and are likely to be more productive (increased weight gains mean young animals come into oestrus earlier). Providing more nutritious fodder also means that the comparatively indigestible parts of cereals (stalks, etc.) that are used as fodder are likely to be better consumed—intake of more fibrous material usually improves with the addition of better quality material to the diet. The potential impact of reduced *S. hermonthica* because of rotation with cowpea has also not been quantified.

Some of the potential contributions of cowpea described above are summarized in Figure 2. In view of these contributions of cowpea and the availability of improved varieties, when seeking to address the opportunities posed by the intensification of crop–livestock systems in the dry savannas, it was apparent that a key component should be improved dual-purpose cowpea varieties. What was equally clear, however, was that cowpea, livestock, or cereal crops never function in isolation in farm fields or households in the dry savannas; likewise, there is a complex of interactions between the biophysical, economic, social, and policy environments that influence farmers' decisions in these environments. As a result of such considerations, in the late 1990s, international and national institutions working on various aspects of component research in the dry savannas began to develop

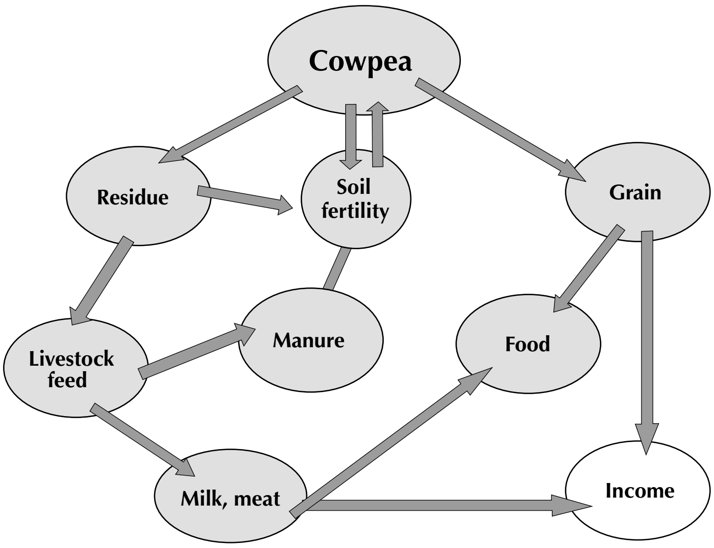

Figure 2. Schematic representation of the potential contributions of cowpea in crop–livestock systems in the dry savannas. Not all potential interactions are shown for simplicity. For example, *dussa* is a regular household product which can contribute to livestock feed. Similarly, other crops and weeds in the system are not shown.

Dussa is the testa of the grain which is separated from the endosperm by soaking prior to pounding and winnowing.

a new approach designed to bring together some of these key elements. This strategy is presented by Tarawali et al. (2000) in the context of natural resource management. In this paper, the emphasis is on the role of cowpea in promoting food and feed production as well as sustainable agriculture.

Development of the research paradigm

The three international research centers with interest in various aspects of the system began meeting to consider how best to initiate such an integrated approach. Scientists from IITA, with the world mandate for cowpea research, ILRI for livestock, and ICRISAT for cereals and groundnut as well as the majority of the dry savanna ecoregion began to plan joint research in 1997. International Fertilizer Development Centre, Niger, with an interest in the soils component of the system, and Center for Overseas Research and Development, University of Durham, UK, with scientists from national research and development institutions have also joined this group more recently. From the outset, there has been consensus among the institutes that the aim of this joint research should be to "improve the lives of farm families in the dry savanna and Sahel of West Africa through sustainable management of the natural resource base for food security and income generation."

The first step in implementing the joint research was the establishment of an experiment at one location in 1998, using existing resources from the institutes involved. At the meeting to plan this research, two major principles were elucidated: first, the idea of "best-bet" options and secondly, a holistic, on-farm approach to evaluate these options. Combining the best of each aspect of the integrated crop–livestock system, varieties, crop geometry, crop residue/manure management, and livestock feeding constituted the best-bet options and it was recognized that these would differ from region to region within the dry savanna, depending on the dominant crop species and management practices. In some regions, sorghum and cowpea would be appropriate, in others, millet and cowpea, etc. Corralling livestock on crop fields may be suitable in some cases but not in others. It was further recognized that, depending on, among other things, market access, it would not be unrealistic to anticipate that some inputs would be available to farmers, and that the options offered, both in terms of the crops used and their arrangement in the field, should seek to maximize the use of available inputs. Implementing this research in a holistic manner meant that not only would crop grain and residue yields be measured, but that the animal performance when fed this fodder and the manure produced to return to the field would be assessed. Furthermore, aspects of nutrient cycling, and the social and economic circumstances and implications of these best-bet options would need to be assessed as a whole.

Implementation of research

The challenges posed by the best bet approach were recognized and so, the initial strategy was to start small and in 1998 the trial was established at just one location in northern Nigeria in Bichi Local Government (8 °19'E; 12 °12'N). This is about 50 km from Kano, on a good road. It was selected because information on village characterization (Ogungbile et al. 1999) from a survey carried out by ICRISAT and IAR in late 1996 was available. Originally, the intention was to use this survey dataset to define various groups of farmers so that representatives of each group could be selected to participate in the trial. However, after describing the aims of the trial to farmers from the village, only 11 volunteered to participate and provided land; it was therefore decided to work with these 11 for the first year. In 1999, an additional 13 farmers participated.

A total of three treatments were established by the participating farmers and in all cases one treatment consisted of the traditional field of sorghum and cowpea (L). Two best-bet options were used; both had improved varieties of cowpea (IT90K-277-2) and sorghum (ICSV 400) and the rows were planted 75 cm apart with four rows of cowpea to two rows of sorghum, in contrast to the farmers' 1 to 1.5 m row spacing and one : one cereal : cowpea geometry. One best-bet option (BB+) included minimum inputs in the form of fertilizer, with nitrogen (N) applied only to the sorghum rows, and insecticide spray (for post-flowering insect pests) applied only to the cowpea; the other best-bet option (BB) had no inputs. It was anticipated that, in addition to maximizing the benefits from cowpea to the soil and minimizing the detrimental effects of sorghum shading on the cowpea, this row arrangement would allow optimal use of scarce inputs. The farmers appreciated the inputs (even though they were required to pay for them) so that in 1999, the BB treatment was modified to include local sorghum but with the same inputs of fertilizer and pesticide. Part of the best-bet options also included the concept of double cropping the cowpea—planting another crop of the same cowpea variety after harvesting the grain and fodder of the first. Previous trials had shown that this could give a good fodder yield with some grain, depending on the rainfall pattern (Singh and Tarawali 1997). All treatment plots received 3 t/ha of manure (1.6% N and 0.7% P) at the start of the 1998 growing season. All operations, land preparation, planting, weeding, application of inputs, harvesting, etc. were carried out by the farmers themselves with some technical guidance from technicians and scientists.

Prior to planting, bulked soil samples were collected from the top 20 cm of soil and analyzed for C, N, and P. Plots were sampled for grain and stover at maturity, using randomly placed quadrants (of about 20 m^2), at the same time they were harvested by the farmers. Samples of grain and biomass were taken for analysis of N and P. When all the sorghum and cowpea residues were dry in the field, they were weighed, collected, and stored in treetops or on house roofs prior to use in the feeding trial. Residues from different treatments were kept separately.

On-farm livestock feeding

During the first part of the dry season, farmers usually release their small ruminants into the fields once the grain harvest is completed to enable them to graze the remaining crop residues and weeds. Once these resources are used up, usually by the middle of the dry season, the animals are tethered within the homestead and fed with the stored crop residues. The initial intention was to tether animals on the respective treatment plots early in the dry season, but farmers indicated that there would be no way to prevent other animals from grazing the plots also, as livestock roam freely once the crop harvest is complete. It was therefore decided to follow the farmers' usual practice and allow free grazing until the weeds and crop residue remaining in situ were used up. Harris (1998) reported that manure deposition on crop fields from free grazing animals is fairly insignificant at an estimated 17 kg/ha. Accordingly, the period for feeding the crop residues harvested from the present experiment began in early February in 1999 and early March in 2000, when the animals were confined to the compounds. By using estimates of 10 kg dry matter per TLU (TLU = Tropical Livestock Unit = 250 kg animal liveweight) per day for a period of 180 days, the recommended liveweight of animals to be fed using the available residue was estimated. The 10 kg daily allowance was made up of a mixture of sorghum and cowpea residues in proportion to the available total weight of biomass of each component on a plot by plot basis. At their suggestion, the farmers provided areas within their compounds where the animals were tethered. In those cases where a farmer had more than one treatment, the area was divided to separate different treatment groups. Animals were tagged; and tags, bowls for feed, and ropes to tie the fodder were color-coded according to treatment. It was recognized that for the L treatment, the fodder was unlikely to be sufficient and farmers were not prevented from providing their own inputs to animals on these treatments, once the material from the experimental plots had been used up. In these instances, the material provided, amounts, and costs were monitored. Even for the animals on BB+ and BB treatments, some farmers opted to provide additional feed resources in the form of *dussa* from millet or sorghum grain. In these instances, the quantities fed were estimated, and samples taken for analysis of N and P. The animals were weighed at the start of the feeding period and thereafter every two weeks. Manure and urine produced during the course of the feeding trial were allowed to accumulate in situ, and kept in the treatment compartment, together with any feed refusals. At the end of the feeding period, in late May, samples of this manure/compost were collected for analysis of N and P. The manure/compost collected during the feeding period was applied to the same treatment plots shortly before planting in 1999.

The costs of inputs used were recorded on a plot by plot basis, and included the planting material, fertilizer, pesticides, purchased manure, and labor. Local market prices for grain and fodder were recorded year round. Information on the sociocultural circumstances relating to farmers' crop–livestock management was also collected during the experiment, largely through village-based technicians and extension officers who interacted closely with both participating and nonparticipating farmers.

In 1999, in addition to the farmers at Bichi, a similar experiment commenced at Unguwan Zangi (8 °05'E, 11 °15'N), a village 60 km northeast of Zaria, in northern Nigeria, with 23 farmers participating. Unguwan Zangi is further south than Bichi, has a longer growing season, and slightly poorer market access. Treatments were the same as for Bichi in 1999, but the varieties were cowpea IT86D-719 and sorghum KSV 8. Unguwan Zangi had been characterized in the medium to high resource use intensity domain as part of a survey carried out in 1997 within the context of the Ecoregional Program for the Humid and Subhumid Tropics of Africa (EPHTA) (Manyong et al. 1998).

Preliminary results

Crop yields

The estimated quantities of cowpea grain and fodder in the BB treatments were greater than those in the local treatment (Fig. 3). The most dramatic difference was for cowpea grain at Bichi in 1998 where the BB+ treatment yielded more than double the BB and about 16 times the L. Fodder yields for BB+ were one and a half times more than BB and five times more than L. In 1999, these differences were less marked, partly because the yields from L were higher. In many instances, although not quantified, this could be related to an increase in the number of farmers adopting some aspects of the best-bet options—varieties and/or cropping patterns. In terms of quantity, the grain and fodder from improved sorghum did not differ much from the local sorghum, but the farmers

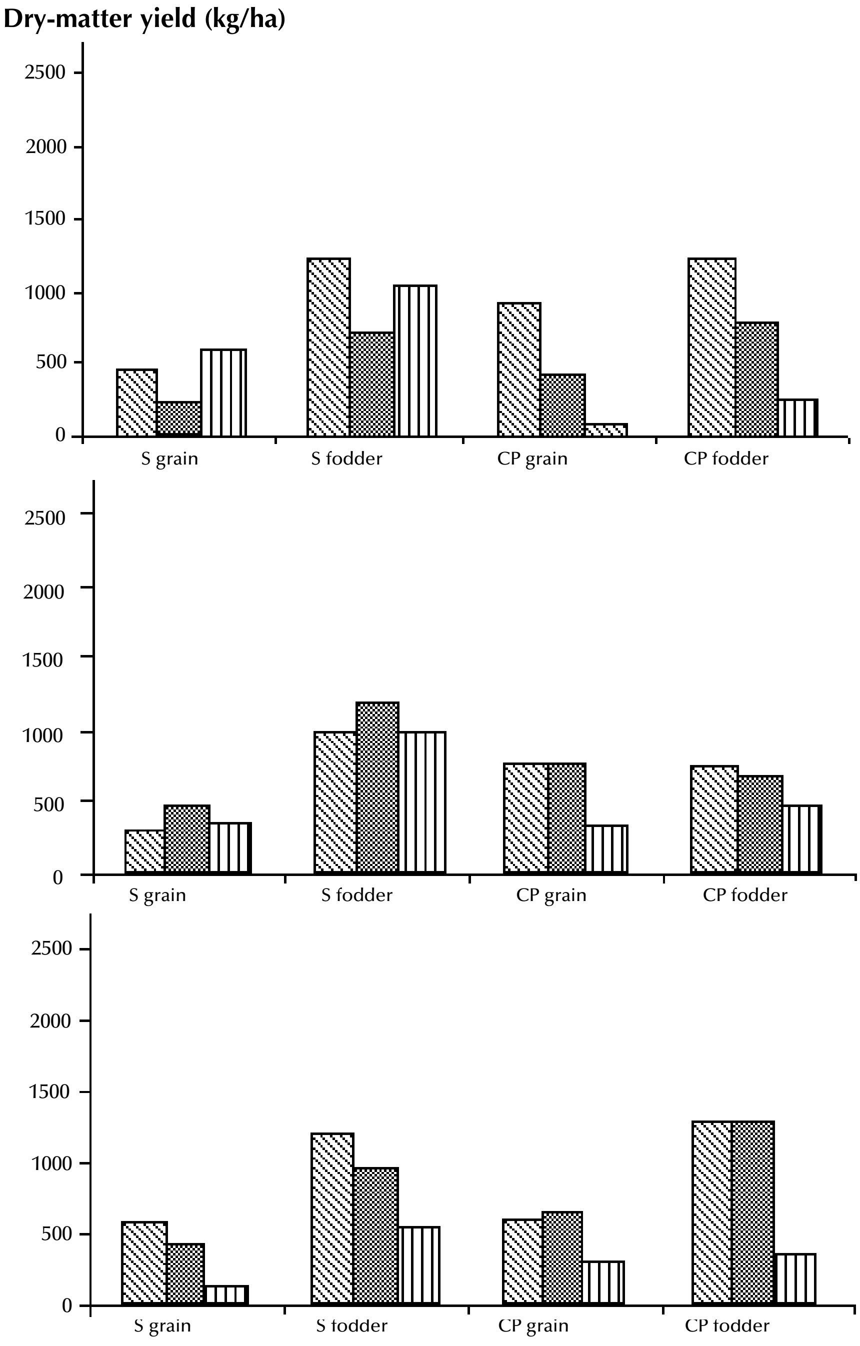

Figure 3. Estimates of dry-matter yields of grain and fodder. From top to bottom, Bichi, 1998; Bichi, 1999; Unguwan Zangi, 1999.
Diagonal hatching: BB+; Solid shading: BB; Vertical hatching: L.

indicated a preference for the improved sorghum, both in terms of cooking quality and time for the grain, and the fodder quality. The farmers' observation of the latter was backed up by analysis that showed about 30% of the local sorghum fodder, which had tall and thick stems, to be edible, compared to at least 60% of the improved, with shorter, thinner stems. Comparing actual fodder yields for both cowpea and sorghum in 1998 indicated that there were considerable losses of the dry fodder during transportation and storage. In some instances, the actual fodder yield when converted to kg/ha was as little as 20% of that predicted from the quadrant harvests. These losses were, to some extent, reduced in 1999 with careful handling, and minimized movement of the fodder for weighing.

Double cropping was not fully implemented to date. In 1998, farmers were reluctant to harvest the first cowpea crop, as the rains, atypically, continued later than usual. This had two effects; one was that the farmers wanted to continue picking the ripe pods and the other was that they did not want to harvest fodder when the environment was still wet meaning the fodder would not dry, but become rotten and be unpalatable to the animals. This limitation was further emphasized by labor requirements for harvesting tomato and pepper on other parts of the farm at the time the second cowpea crop was to be planted. A few farmers at Bichi in 1999 and 1998 implemented double cropping and were able to harvest both grain and fodder. At a recent field day, samples of fodder from the second cowpea crop were compared visually with those from the first. Farmers agreed that the second crop was clearly of better quality, based on a visual comparison of the leafiness and greenness—criteria they usually use to assess fodder quality.

Livestock productivity

For livestock feeding, using the fodder harvested in 1998 to feed small ruminants during the 1998/99 dry season, only eight farmers at Bichi were able to participate so the results should be viewed with some caution, considering also the farm-to-farm variation. These preliminary data indicated that animals on the BB+ treatment gained significantly more weight during the last six weeks of the 16-week feeding period than those on BB or L (Fig. 4). Overall, the average liveweight gains (averaged over all farmers) were 3.54 kg per animal for BB+, 0.91 kg (BB) and 2.19 kg (L). While manure quantities produced by animals on the different treatments (manure here is used to refer to the manure plus feed refusals—all that was collected and returned to the field) did not differ significantly, the N content was 1.35% (BB+) 1.09% (BB) and 0.80% (L). P contents were estimated as 0.28% (BB+) 0.27% (BB) and 0.25% (L). These values are within the ranges reported by Tarawali et al. (2001).

Figure 4 shows the preliminary results from livestock feeding trials in the 1999/2000 dry season at Bichi (17 farmers participating) and Unguwan Zangi (11 farmers). At Bichi, again the BB+ was superior to BB or L, but at Unguwan Zangi it appeared that the two best-bet options were better than the local, but not different from each other. Average weight changes (kg) per animal over the entire feeding period at Bichi were 1.75 (BB+), 0.28 (BB), and 0.03 (L), representing gains of 8, 1.3, and 0.1%. At Unguwan Zangi, there were slight weight losses for BB+ (0.74 kg) and L (0.78 kg), whereas animals on BB gained an average of 0.9 kg per animal.

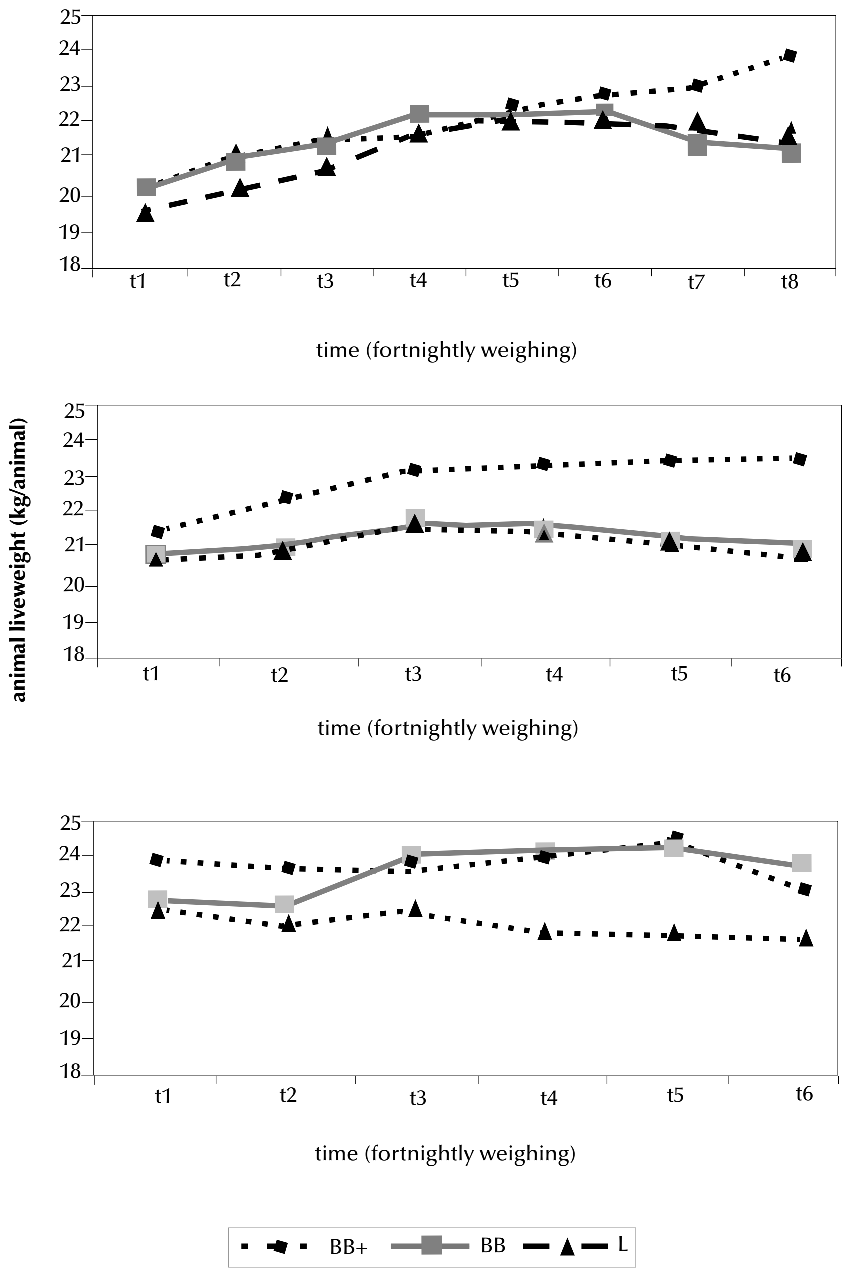

Figure 4. Average liveweight (kg/animal) for livestock feeding trials. Upper graph Bichi 1998/1999; center graph Bichi 1999/2000; lower graph Unguwan Zangi 1999/2000.

Nutrient dynamics

Using data from the eight farmers who participated in the feeding trial at Bichi in 1998, it is possible to look at some aspects of nutrient dynamics in these integrated options (Table 2). In simple terms, for nitrogen (N) and phosphorus (P), the inputs have been considered as the soil status for these elements at the time of trial establishment, the manure and fertilizer added, and a small input of P from the harmattan dust (Harris 1998). Outputs are the nutrients removed in grain and fodder. At present, there has been no attempt to take account of nutrient loss through leaching, volatization, etc. These figures are within the range reported by Harris (1998) for similar farmers' fields in the Kano region and indicate that both N and P balances were positive at the end of the growing season. It would appear that the cowpea removed more nutrients than the sorghum, or this could be interpreted that the cowpea used the added nutrients more effectively than the sorghum. The strong positive balances are surprising and could be attributed to a number of factors. As indicated above, the N and particularly the P concentrations in the applied manure were quite high, compared to results in other reports (Tarawali et al. 2001). Furthermore, since leaching and volatilization were not considered, it may be inappropriate to include the initial soil N and P and the contribution from P in the harmattan dust. If these factors are excluded, and the manure N contents reduced to 1.5 and P to 0.2%, then the balances are only just positive (Table 2). This information is at present inadequate to enable estimation of the role of cowpea in promoting nutrient cycling, and the nutrient balances need to be monitored for several more seasons, including the returns to the system from the manure and crop residue refusals, removal of subsequent crop harvests, etc. At this point, the emphasis is that nutrient dynamics is being monitored in these studies and should provide quantitative information on whether nutrients are being mined by this more intensive production system, if the applied nutrients are being optimally used, and how the improved options compare with farmers' traditional systems.

Economics

The objective of the economic evaluation is to compare the costs, returns, and profits among the three treatments as a basis for further assessing the desirability of introducing the best-bet options. Although a whole system analysis is planned, as an example, only a partial result on the treatments is presented here, based on the results of the crop yields in 1999 at Bichi. This approach will subsequently be expanded to include an estimation of the value of the livestock products (increased liveweight and manure nutrients), rather than, as treated in this example, considering the monetary value of the crop residues as if they were all sold. In order not to bias the comparison between the improved and local varieties, average market prices for the study area were used for inputs and outputs. Labor data were collected separately for hired and family labor and include the cost of ridging, planting, spraying, fertilizer application, weeding, remolding, and harvesting. Material costs include fertilizers, insecticide, seeds, and manure.

Results of the partial economic analyses are summarized in Table 3. Because farmers use a lot of family labor (about 70% of the total for most operations), the cost of which is often not estimated, figures are presented for both total costs which includes an estimate of family labor, and the actual costs where this value is excluded. One of the most striking features is the difference in costs for labor and materials between BB+ and BB. In 1999, the only difference between these two options was that BB+ had improved sorghum and

Table 2. Estimated nitrogen and phosphorus inputs and outputs (kg/ha) during the first year of the trial at Bichi (1998).

	BB+		BB		L	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Inputs						
Soil	7.9	0.1	7.8	0.1	8.3	0.1
Manure (1.6% N; 0.7% P)	48.0	21.0	48.0	21.0	48.0	21.0
Inorganic fertilizer	35.0	15.0	0.0	0.0	0.0	0.0
Harmattan dust		0.8		0.8		0.8
Total inputs	90.9	37.0	55.8	22.0	56.3	21.9
Outputs						
Sorghum grain	6.6	0.9	5.0	0.7	6.1	0.9
Sorghum fodder	3.8	0.8	3.4	1.0	5.0	0.8
Cowpea grain	27.8	2.2	19.7	1.6	1.7	0.1
Cowpea fodder	16.5	2.0	12.1	1.2	10.4	1.1
Total outputs	54.6	5.9	40.1	4.6	23.2	2.9
Balance	36.4	31.1	15.7	17.4	33.2	19.1
Balance with 1.5% N and 0.2% P, excluding soil and harmattan	25.4	15.1	4.9	1.4	21.8	3.1

BB+ = Best bet option with inputs.
BB = Best bet options without inputs.
L = Traditional sorghum and cowpea.

Table 3. Summary of partial economic analyses for the three treatments. Total costs include the value of family labor, which is not accounted for in the values for actual costs.

	BB+	BB	L
Total cost			
Total revenue	32 069	35 181	19 872
Materials	8 746	10 796	4 767
Labor	12 581	16 675	10 644
Total costs	21 327	27 471	15 411
Gross margin	10 742	7 710	4 461
Benefit : cost ratio	1.50	1.28	1.29
Actual cost			
Total revenue	32 069	35 181	19 872
Materials	8 746	10 796	4 767
Labor	3 355	3 617	3 004
Total cost	12 101	14 413	7 771
Gross margin	19 968	20 768	12 101
Benefit : cost ratio	2.65	2.44	2.56

Values are all in Naira/hectare (at the time of writing, ₦100 = US$1.00).

BB local sorghum. Closer analysis of the information reveals that BB has 23% more material costs, with the highest component of this being a 30% increase in the cost of seed. Labor costs were even more different, with BB having 32% more labor costs than BB+. Within these costs, BB had higher costs than BB+ for remolding (86%), harvesting (34%), and weeding (39%). It can be speculated that these differences are related to the higher yield of the local sorghum and its tall stature (this could have necessitated more remolding to make sure the tall stalks did not get blown over late in the season). Because the local sorghum plants are generally bigger than the improved variety, they may have been planted less densely and therefore more space between plants could have meant more weeding. Alternatively, moving through these taller plants to weed could have been more difficult and therefore more time consuming. While BB+ required 38% more inputs than L, the revenue was 77% more, indicating that increased yields amply compensated for the investment in fertilizers and insecticides.

Total revenue from the crop enterprise (grain and fodder) was highest for BB, followed by BB+, representing increases of 77 and 61% respectively, over L. Income differences related almost entirely to differences in yield. All treatments, in both scenarios including and excluding family labor gave positive gross margins and benefit cost ratios greater than one, indicating that the system as a whole is quite profitable. BB+ had the highest benefit–cost ratio.

For both the best-bet treatments, about 70% of the revenue was from cowpea grain and fodder, with the balance being contributed by the sorghum component. By contrast, 59% of the revenue in the L treatment was obtained from cowpea. About one-fifth of the cowpea revenue in BB+ and BB was contributed by cowpea fodder, but as much as 25% of the cowpea revenue in the L treatment was from fodder. Such considerations suggest that it may be more profitable for a farmer to grow only cowpea, if maximum profit is the aim. Indeed, hypothetical calculations comparing potential partial budgets from 100% cowpea or 100% sorghum fields, based on these figures, give higher benefit–cost ratios for cowpea only 1.82 (BB+); 1.42 (BB), and 1.46 (L). If only sorghum were to be grown, benefit-cost ratios fall to 1.20 (BB+), 1.28 (BB), and 1.3 (L). Nevertheless, it is important to keep these hypothetical examples in the context of the family needs; no farmer could afford not to grow some sorghum because it is the staple family diet. This stresses the importance of considering not only the economic values, but the social context of the introduced technologies. It could also be argued that maintaining the intercropping system used by farmers ensures some degree of risk diversification.

A win-win situation?

In Nigeria, with an estimated 4 million ha planted annually to cowpea (FAO 2000), if we were to estimate that the best-bet options would be appropriate for one-third of this, and take the lower figure of a doubling in grain yield and apply it to the 538 kg/ha average national yield (FAO 2000), the implication would be an increase of 0.7 million tonnes of cowpea grain. Applying similar speculations to livestock figures, Winrock (1992) estimates 56% of the goats and 64% of the sheep in sub-Saharan Africa are in the dry savannas. If these estimates are applied to current FAO figures for the numbers of sheep and goats in Nigeria (FAO 2000), then an estimate is obtained of 13.6 million goats and 13.1 million sheep in the dry savannas of Nigeria. From the livestock feeding trials carried out in Bichi in 1998/99, those animals on BB+ gained 1.6 times more weight than the local treatment animals. If the intervention were to reach one-third of the small ruminants in the Nigerian dry savanna, this would mean 8.9 million animals gaining an extra 1.35 kg each per annum, a total of 11.6 million kg liveweight—in the region of 5 million kg of extra meat, or 0.6 million animals. If these 0.6 million animals produced manure at the rate of 1 kg/day/TLU and a nitrogen content of 7%, this could represent about 12 000 tonnes of nitrogen (although this figure does not take account of volatilization or leaching). Clearly, these figures are really speculation, and it is not possible to put a time scale on the adoption of these interventions at this point. Furthermore, these are based on calculations of productivity alone, and it is important to recollect that the aim of the best-bet options is not solely to increase productivity, but to do so in a way that is sustainable and does not destroy the natural resource base, as well as being economically and socially attractive to farmers.

In this context, it is important to take into consideration the nutrient dynamics, and to ask whether we are really intensifying production without mining the soil. This question requires several years of data to answer, and there are opportunities to continue to optimize the nutrient use. In order to identify what some of these options might be, complementary trials have been carried out in Niger, where, in farmer-managed trials involving 10 farmers in the Sahelian zone at Sadoré, hill placement of small quantities of fertilizers and broadcasting of phosphate rock of Tahoua were compared with farmers' practices in continuous, intercropping, and rotation systems. The farmers' practices without any input yielded 497 kg/ha of millet grain whereas about an additional 300 kg/ha was obtained with broadcasting of locally available phosphate rock of Tahoua plus 4 kg P/ha of compound P fertilizers. With the addition of nitrogen fertilizers, whereas in continuous cropping, 881 kg/ha of millet grain was harvested, 1135 kg/ha was obtained when millet was rotated with cowpea. In the intercropping system, in addition to 858 kg/ha of millet grain, 234 kg/ha of cowpea grain was harvested. It is important to note that the benefit of selling the cowpea grain will be enough to purchase the needed external inputs in this case.

The calculations of partial budget data, based on the crop yields only, suggest that the best-bet options are profitable for farmers. Including the livestock values in the calculations is likely to enhance this even further. In trials established in 2000, the introduction of improved cowpea grain storage methodology, using a simple triple bagging method (Murdock et al. 1997) is anticipated to increase income from cowpea grain even more. By storing the cowpea grain without fear of insect attack, farmers can keep the grain for at least three months when the price could increase by as much as threefold.

Semistructured interviews with participating farmers are planned during 2000 and 2001 in order to assess the social context into which these interventions fit, and to better elucidate farmers' perceptions and priorities.

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References

Badiane, O. and C.L. Delgado. 1995. A 2020 vision for food, agriculture, and the environment in sub-Saharan Africa. International Food Policy Research Institute (IFPRI), Washington DC, USA. 56 pp.

Bagayoko, M., S.C. Mason, and S. Traoré. 1998. The role of cowpea on pearl millet yield, N uptake and soil nutrient status in millet–cowpea rotation in Mali. Pages 109–114 *in* Soil fertility management in West African land-use systems, edited by G. Renard, A. Neef, K. Becker, and M. von Oppen. Margraf Verlag Weikersheim, Germany.

Berner, D.K., R.J. Carsky, K.E. Dashiell, J. Kling, and V.M. Manyong. 1996. A land management-based approach to integrated *Striga hermonthica* control in sub-Saharan Africa. Outlook on Agriculture 25: 157–164.

Carsky, R.J. and D.K. Berner. 1995. Benefits of crop rotation with soybean and cowpea in savanna cereal-based systems. Pages 391–402 *in* Technology options for sustainable agricultural production in sub-Saharan Africa, edited by T. Bezuneh, A.M. Emechebe, J. Sedgo, and M. Ouédraogo. Semi-Arid Food Grain Research and Development (SAFGRAD), Ouagadougou, Burkina Faso.

Delgado, C., M. Rosegrant, H. Steinfeld, S.K. Ehui, and C. Courbois. 1999. Livestock to 2020. The next food revolution. Food, Agriculture and the Environment Discussion Paper 28. International Food Policy Research Institute (IFPRI), Washington DC, USA; Food and Agriculture Organization of the United Nations (FAO), Rome, Italy; and International Livestock Research Institute (ILRI), Nairobi, Kenya.

de Haan, C., H. Steinfeld, and H. Blackburn. 1997. Livestock and the environment. Finding a balance. Report of a study coordinated by FAO, USAID, and the World Bank. FAO, Rome, Italy.

Ehui, S., H. Li Pun, V. Mares, and B. Shapiro. 1998. The role of livestock in food security and environmental protection. Outlook on Agriculture 27: 81–87.

FAO. 2000. FAOSTAT Database. http://apps.fao.org Food and Agriculture Organization of the United Nations, Rome, Italy. Accessed June 2000.

Harris, F. 1998. Farm-level assessment of the nutrient balance in northern Nigeria. Agriculture, Ecosystems and Environment 71: 201–214.

ICRISAT. 1991. ICRISAT West African program annual report. 1990. International Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, Niamey, Niger.

ILRI. 2000. ILRI strategy to 2010. Making the livestock revolution work for the poor. International Livestock Research Institute (ILRI), Nairobi, Kenya.

McIntire, J., D. Bourzat, and P. Pingali. 1992. Crop–livestock interaction in sub-Saharan Africa. World Bank, Washington DC, USA.

Manu, A., T.L. Thurow, A.S.R. Juo, I. Zanguina, M. Gandah, and I. Mahamane. 1994. Sustainable land management in the Sahel: a case study of an agricultural watershed at Hamdallaye, Niger. TropSoils Program, Soils and Crop Sciences Department, Texas A & M University, USA.

Manyong, V.M., K.O. Makinde, and J.O. Olukosi. 1998. Delineation of resource-use domains and selection of research sites in the northern Guinea savanna ecoregional benchmark area, Nigeria. Paper presented during the launching of the northern Guinea savanna ecoregional benchmark area, 2 December 1998. Institute of Agricultural Research (IAR), Zaria, Nigeria. IITA, Ibadan, Nigeria.

Murdock, L.L., R.E. Shade, L.W. Kitch, G. Ntoukam, J. Lowenberg-DeBoer, J.E. Huesing, W. Moar, O.L. Chambliss, C. Endondo, and J.L. Wolfson. 1997. Postharvest storage of cowpea in sub-Saharan Africa. Pages 302–312 *in* Advances in cowpea research, edited by B.B. Singh, D.R. Mohan Raj, K.E. Dashiell, and L.E.N. Jackai. Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Naazie, A. and J.W. Smith. 1997. Modelling feed resources budgets in the moist savannas of West Africa. Pages 197–198 *in* Proceedings of the XVIII International Grassland Congress, June 1997, Winnipeg and Saskatoon, Canada.

Ogungbile, A.O., R. Tabo, and N. van Duivenbooden. 1999. Multiscale characterization of production systems to prioritize research and development in the Sudan savanna zone of Nigeria. (summary in English and French). Information Bulletin no. 56. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Andhra Pradesh, India. 112 pp.

Okike, I., M.A. Jabbar, V. M. Manyong, J.W. Smith, J.A. Akinwunmi, and S.K. Ehui. 2001. Agricultural intensification and efficiency in the West African savannas: Evidence from northern Nigeria. Socioeconomics and Policy Research Working Paper 33. International Livestock Research Institute (ILRI), Nairobi, Kenya. 54 pp.

Ousman Badiane, O. and C.L. Delgado (editors). 1995. A 2020 vision for food, agriculture and the environment. International Food Policy Research Institute (IFPRI), Washington DC, USA.

Schlecht, E., F. Mahler, M. Sangaré, A. Susenbeth, and K. Becker. 1995. Quantitative and qualitative estimation of nutrient intake and faecal excretion of Zebu cattle grazing natural pasture in semiarid Mali. Pages 85–97 *in* Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, edited by J.M. Powell, S. Fernández-Rivera, T.O. Williams, and C. Renard. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

Singh, B.B., O.L. Chambliss, and B. Sharma. 1997. Recent advances in cowpea breeding. Pages 30–49 *in* Advances in cowpea research, edited by B.B. Singh, D.R. Mohan Raj, K.E. Dashiell, and L.E.N. Jackai. Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Singh, B.B. and S.A. Tarawali. 1997. Cowpea and its improvement: key to sustainable mixed crop–livestock farming systems in West Africa. Pages 79–100 *in* Crop residues in sustainable mixed crop–livestock farming systems, edited by C. Renard. International Crops Research Institute for the Semiarid Tropics (ICRISAT), International Livestock Research Institute (ILRI), and CAB International, Wallingford, UK.

Tarawali, S.A., B.B. Singh, M. Peters, and S.F. Blade. 1997. Cowpea haulms as fodder. Pages 313–325 *in* Advances in cowpea research, edited by B.B. Singh, D.R. Mohan Raj, K.E. Dashiell, and L.E.N. Jackai. Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Tarawali, S.A., J.W. Smith, P. Hiernaux, B.B. Singh, S.C. Gupta, R. Tabo, F. Harris, S. Nokoe, S. Fernández-Rivera, and A. Bationo. 2000. Integrated natural resource management—putting livestock in the picture. Paper presented at the Integrated Natural Resource Management meeting, 20–25 August 2000, Penang, Malaysia.

Tarawali, S.A., A. Larbi, S. Fernández-Rivera, and A. Bationo. 2001. The role of livestock in the maintenance and improvement of soil fertility. Pages 281–304 *in* Sustaining soil fertility in West Africa, SSSA Special Publication No. 58. Soil Science Society of America and American Society of Agronomy, Madison, USA.

Winrock. 1992. Assessment of animal agriculture. Winrock International, Morrilton, Arkansas, USA.