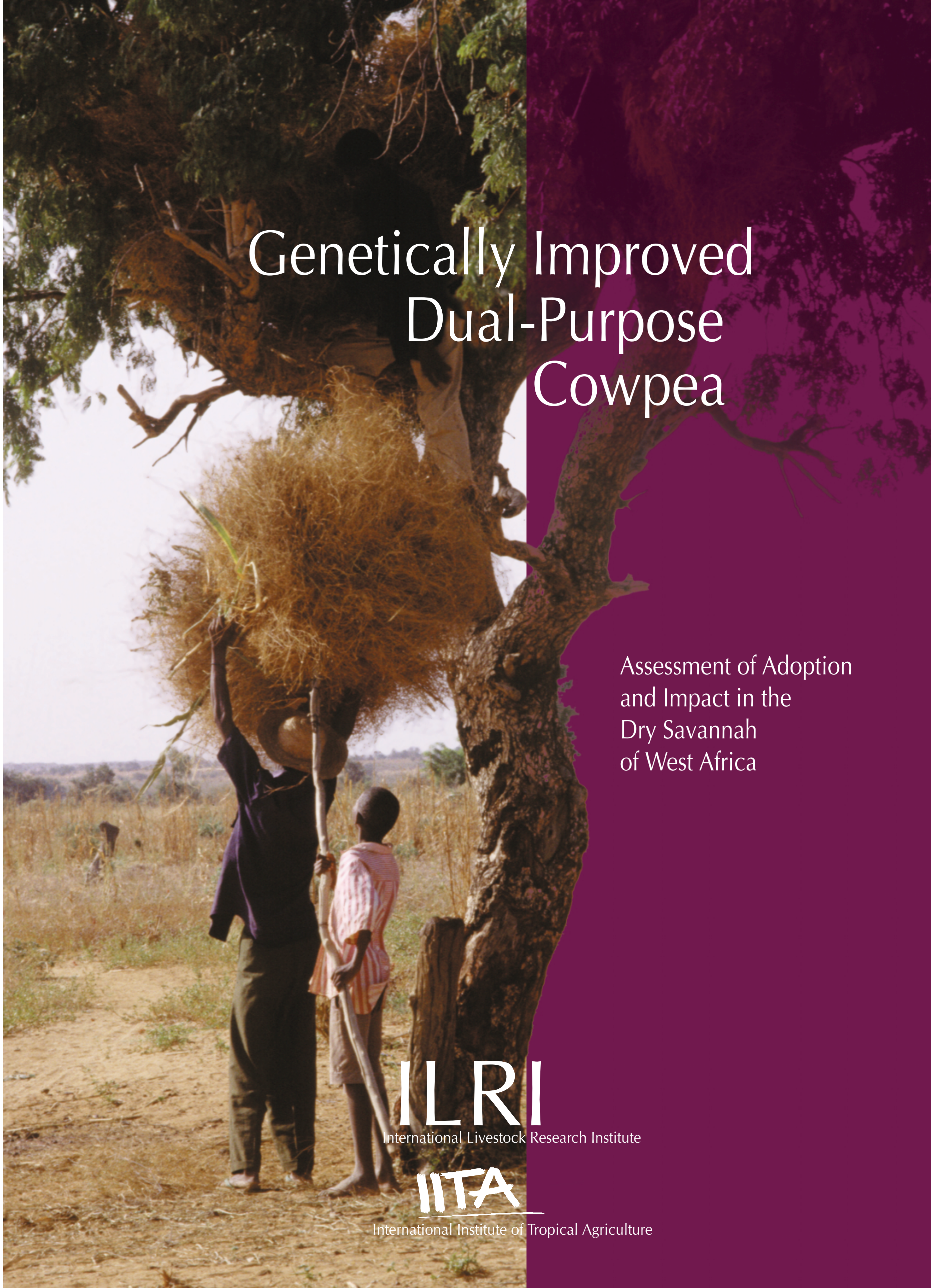

Genetically Improved Dual-Purpose Cowpea

Assessment of Adoption and Impact in the Dry Savannah of West Africa

ILRI
International Livestock Research Institute

IITA
International Institute of Tropical Agriculture

Genetically Improved Dual-Purpose Cowpea:

Assessment of Adoption and Impact

in the Dry Savannah Region of West Africa

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Table of Contents

List of tables

List of figures

Abstract

The research reported here has the potential for contributing to a real improvement in the livelihoods of mixed crop–livestock farming households in the dry savannah zone of West Africa through widespread uptake of improved dual-purpose cowpea (IDPC). This technology offers opportunities for the production of more, higher-quality food for poor people and fodder for animals, along with soil-fertility improvement and other social benefits. The study examines issues surrounding the adoption and impact of the new varieties and associated management strategies. A novel approach was taken, combining GIS, a crop model, and household, community and participatory research approaches in northern Nigeria in order to address the following questions: 'What types of impact are expected and their magnitude, where is the impact most likely to be felt, and by whom?'

The results suggest that the research investment has been beneficial, and the expected returns are high. Furthermore, the steps taken in order to quantify the benefits versus the costs of this research have identified for researchers, policy makers and development practitioners important considerations and possibilities for speeding up and widening the impact of this technology. First, it is a flexible technology that is appreciated by, and will have the greatest impact on, farming households that are usually poor and living in remoter areas where improved crop and livestock production are especially critical to livelihood strategies. Although the wealthiest households are more likely to be adopters, poorer households have also taken up IDPC. As it is the poorer households that cultivate 75% of the arable land, the potential impact of extending the technology to these more rural, less market-oriented households is huge.

Uptake to date has been more likely to occur near wholesale markets in the most densely populated areas. Thus, finding innovative ways to increase access to markets and provide improved seeds and information for farmers in low-population density areas may have potentially large payoffs. The benefit from investment in rural market infrastructure and roads will be reflected in increased uptake of natural-resource-enhancing technologies such as IDPC. Farmer-impact workshops were held and the results pointed towards environmental- and poverty-impact indicators that can be monitored as people experiment with, and adapt, the new varieties and associated management techniques.

The study has highlighted opportunities relating to the identification of the benefits of IDPC for livestock which are likely to emerge when data from several years of ongoing integrated crop-livestock trials become available.

Given the population, climatic and land-use changes that are likely to occur in West Africa in the coming decades, there is an onus on researchers to streamline the effectiveness of R&D activities so that they benefit the rapidly increasing numbers of poor people in the region. The lessons learnt from the impact assessment study reported here will have much broader applicability in the future than to cowpea research alone. It is hoped that this analysis provides a research and impact-assessment strategy that will be

useful for other crops and technologies, and in particular that it provides guidelines for assessments of more integrated natural resource management strategies (including livestock) and technologies. Most importantly, the novel multidisciplinary, multicentre and participatory approaches taken by the cowpea research team are helping to close the researcher–farmer feedback loop. Ultimately this is what will lead to faster and more widespread adoption and impact of new technologies.

1 Introduction

This comprehensive *ex ante* impact assessment examines the adoption and impact of genetically improved cowpea varieties in the dry savannah region of West Africa. There are many reasons why the leguminous crop cowpea *(Vigna unguiculata (*L.) Walp.*)* is seen as being an encouraging option for increasing food and feed production in relatively dry areas. IITA in collaboration with ILRI developed genetically improved dual-purpose cowpea (IDPC) varieties with the aim for producing grain for humans, have been developed that produce both more food and more high-quality fodder for livestock and contributing to soil fertility (Singh and Tarawali 1997; Singh et al. 1997; Iniazumi et al. 1999). It appears that there are good prospects for widespread uptake of these new varieties to occur across the dry savannah regions of West Africa. This report examines that potential through multiple research approaches that have been undertaken by ILRI and partners at different spatial scales over several years, including at farm-household, community, national and regional levels.

The objectives of the assessment were to:

1. Describe the economic, social and environmental benefits of IDPC in the various farming systems where this crop is currently an important part of farmers' crop–livestock systems. This involves examining adoption patterns in areas where the new varieties are being taken up in order to predict adoption rates and lags across wider areas. Given the multiple benefits of IDPC, it also means exploring new approaches that will allow quantification and valuation of livestock and environment-related impacts in future analyses.
2. Quantify, where possible, these benefits as well as the costs of the research and extension efforts under way, and measure the potential returns to the research investment.
3. Establish baseline data on area planted and production levels (grain and fodder) of IDPC to provide information for future ex post impact assessments that will measure the actual adoption and impact of new varieties developed through this research.
4. Contribute to, and identify gaps in, the knowledge base concerning impacts of IDPC in farming systems and to indicate how some of these gaps might be filled.

This assessment was undertaken to provide information for researchers and policy makers for research priority setting, technology targeting and dissemination efforts. Given the multiple benefits that individuals and communities report deriving from the new varieties (Okike et al. 2001; Kristjanson, Place et al. 2001), the goal is to increase uptake speed and spread of IDPC in the target areas identified in this study, and to demonstrate that communities and households can derive benefits that outweigh the costs of this new technology.

2 Background

2.1 Evolving crop livestock systems

The human population in sub-Saharan Africa (SSA) continues to rise. This region has one of the highest rates of population growth in the world and is anticipated to have a population of 1.4 billion by 2050 (Thornton et al. 2002). A shift in the proportion of urban dwellers is also anticipated, with around 50% of the population expected to be living in urban areas by 2025, compared to less than 30% in 1990 (Winrock 1992). At the same time, and partly in response to the increased livestock demand associated with urbanisation (Ehui et al. 1998), it is anticipated that livestock numbers will also increase dramatically over the next few decades (Delgado et al. 1999). In West Africa, where over 40% of SSA's population live (FAO 2000), there is high and increasing pressure to expand and intensify agricultural production to meet the rising demand for food. The integration of crop and livestock production is one response to such increased pressure (McIntire et al. 1992; Ndubuisi et al. 1998). In 2000, only 5% of West Africa's human population of 255 million was found in livestock-only, rangeland-based livestock systems (i.e. pastoral), compared to 80% in mixed crop–livestock rainfed systems, and these proportions are expected to be the same in 2050 (Thornton et al. 2002). It is predicted that in 2050 West Africa will have 562 million people, and 237 million of these (42%) will live in Nigeria (Kristjanson, Thornton et al. 2001).

Across West Africa researchers find the following typical scenario: as crop farmers seek to increase their production, crops are planted on more marginal land and fallow periods are reduced, resulting in an increased demand for inputs, especially fertilisers. Inorganic fertilisers are often hard to come by and expensive, therefore farmers increasingly seek to fulfil their soil nutrient needs by obtaining manure from the herds of nomadic or transhumant livestock keepers. Faced with the increasing demand for livestock products, and yet a reduction in grazing resources on marginal or fallow lands, livestock keepers rely on crop residues as their major feed resource (Naazie and Smith 1997). These trends tend to promote the integration of crop and livestock production on the same farm, and various stages in the evolution of such crop–livestock systems have been examined (Jagtap and Amissah-Arthur 1999). In West Africa, this integration of crop and livestock enterprises is taking place on both a temporal and a spatial scale. At present there is a north-south gradient of decreasing integration that gives us a spatial representation of what is happening over time – the southward movement of closer integration. Of course, there is considerable variation within these gradients, with a whole host of factors coming into play, notably market access and population density.

2.2 Crop–livestock systems in the dry savannahs of West Africa

In the dry savannah region of West Africa, where 108 million people, 22 million cattle and 65 million sheep and goats are found (see Table 3, described in Section 3.3), there is a need to better integrate crop and livestock production. The region consists of the drier part of the northern Guinea savannah, plus the Sudan savannah. These areas have an annual rainfall of less than 1000 mm, a long (7- to 9-month) dry season, and a length of growing period (LGP) of 90–180 days (see Figure 3, described in section 3.3). The soils are very poor in terms of fertility (especially nitrogen, phosphorus and organic carbon), and nutrient mining related to repeated cropping and low input availability is a major concern (Buerkert and Hiernaux 1998).

Crop production in the dry savannahs is cereal-based. Sorghum and millet are the principal cereals, with millet being more common in the drier, more northerly part of the region. The majority of farmers practice intercropping of cereals with grain legumes, usually cowpea or groundnut. Crop grain provides food and income for household members, but the residues from both the cereals and the grain legumes constitute an essential source of fodder for their cattle, sheep and goats. Livestock, in turn, provide manure, milk, traction and a source of cash income. Farmers are well aware of the importance of residues for their livestock, and deliberately adopt cropping strategies and use crop varieties that will ensure some fodder is available, even at the expense of grain yield. A common strategy, for example, is for a farmer to alternate planting rows of traditional grain-type cowpea with fodder-type cowpea between the sorghum rows using a low plant density (Singh and Tarawali 1997). The planting pattern may be complicated by the inclusion of millet and/or groundnut. Following harvest of the sorghum and grain-type cowpea, the fodder cowpea is left to spread over the field until the rains cease completely and there are signs of wilting. At this point the fodder is harvested (any grain is considered a bonus) and rolled in bundles to be stored in trees or on house roofs. Fodder is used to feed the ruminant livestock at the peak of the dry season when cowpea fodder, with its superior nutritional quality compared with cereals, is especially valued. Indeed, some farmers are able to sell fodder to generate income, and there have been reports of up to 25% of a farmer's annual income coming from sales of cowpea fodder (ICRISAT 1991).

2.3 Cowpea in West Africa

Cowpea is an important crop in West Africa. FAO figures suggest the total harvested cowpea acreage in West and Central Africa has increased from 4 million hectares in 1988 to an estimated 9.4 million hectares of land in 2000 (Figure 1). Although agricultural production statistics in the developing world, particularly for an under-reported crop such as cowpea, may be somewhat unreliable, this appears to represent a significant proportion of the global total of some 12.5 million ha (Singh et al. 1997).

Ortiz (1998) suggested that in the mid-1990s the cowpea production area of Nigeria and Niger together accounted for 87% of world cowpea production area. While cowpea grain is an important product – it has been estimated that from 1961 to 1995 cowpea grain production in Nigeria increased by over 400% (Ortiz 1998, and Figure 1, which shows a 107% increase in grain production from 1988 to 2000) – productivity levels remain very low, typically less than 500 kg/ha. In view of such low yields, the popularity of cowpea may appear paradoxical, but researchers working with the crop attribute its popularity with farmers to the multiple roles that cowpea plays within these farming systems, roles that become more important as agriculture intensifies and crop and livestock production become more closely integrated (Mortimore et al. 1997). As described above, cowpea fodder is an important product (although there are little or no regional or national statistics available on cowpea fodder production or sales, thus this assertion is largely a result of researchers' observations and various farm and market-level surveys), and many farmers do not mind sacrificing some grain yield in order to be sure that they will have fodder for their livestock. Well-fed livestock in turn provide meat, milk and traction, but also manure that contributes towards the sustainability of the farming system. In many cases, this manure may be the only input used to replenish the fragile soils. As a legume, cowpea also contributes to soil fertility directly through nitrogen fixation, and even though the above-ground biomass is removed for fodder, the roots and any fallen leaves can make a significant difference to subsequent cereal yields (Manu et al. 1994; Carsky and Berner 1995; Bagayoko et al. 1998; Carsky and Vanlauwe 2002). Rotation with cowpea also helps to reduce the seed bank of *Striga hermonthica*, a parasitic weed of cereals that can cause up to 100% loss of grain yield (Berner et al. 1996).

2.4 The research strategy

Given these multiple roles, and its contribution to both human nutrition and livestock production, it is apparent that cowpea can make a significant contribution to agricultural production, even when there is pressure to produce more crops and livestock from the same land resources, as is the situation in the dry savannahs. In view of this, from the early 1990s IITA cowpea scientists diversified the breeding objectives to include development of dual purpose varieties that would give both grain and fodder and forged collaboration with ILRI to ensure enhanced fodder quality. If such cultivars could be developed/identified, then farmers would have the opportunity to replace their traditional grain and fodder types with a variety that would give both superior grain yield and a reasonable quantity of fodder. In this way, farmers would obtain more grain because the area usually under fodder-type cowpea would now produce grain. They would also end up with more fodder because the area usually under grain-type cowpea would now produce fodder.

It was on this basis that ILRI and IITA scientists began to work together, including fodder quantity and quality parameters among the cowpea selection criteria, in addition to grain yield, in the latter's cowpea breeding programme (Tarawali et al. 1997). Some promising dual-purpose varieties – with good grain and fodder yields for the dry savannahs – were identified (Singh and Tarawali 1997; Singh et al., 1997). During the course of developing and testing the dual-purpose cowpea, IITA scientists found that the new varieties could produce more grain than the local grain types of cowpea – even in the absence of insecticide spray – plus a reasonable quantity of fodder. Most of the new dual-purpose varieties produce as much fodder as local fodder varieties in use, with higher grain yield – which the local fodder types do not. Furthermore, these dual-purpose varieties can easily be managed in a way that can influence the end balance between grain and fodder yield – picking pods several times will result in less fodder than if pods are picked only once or twice, for example. Farmers can also choose to practice 'double cropping' where all the grain is harvested from the first planting and another crop is planted late in the season to supply fodder. This is an added attraction of these varieties in that it places choices between grain and fodder production in the hands of the farmers, and they can make appropriate adjustments according to weather and pest conditions. An additional advantage of dual-purpose cowpea varieties is that it is anticipated that the introduction of the new seeds to farmers will be relatively straightforward. It is not a new technology, but rather an improvement on what they already do and are familiar with. Furthermore, within the West African region, networks of international and national cowpea scientists are already in place that can facilitate the dissemination of both the varieties developed and the concept of including fodder characteristics in the breeding and selection criteria.

In view of the importance of cowpea in Nigeria, and the ongoing research and development efforts for this crop in the northern region of the country in particular, ILRI and IITA decided to focus the detailed survey research in that area, then to extrapolate across West Africa. While it could be argued that Nigeria's high population and the presence of more intensive IITA-led cowpea research efforts potentially introduce biases within our sample, it was felt that this was a forward-looking strategy bearing in mind that the current population and resource pressure (e.g. lack of fallow) in northern Nigeria is likely to be faced by most of the other West African countries in the next two decades (Thornton et al. 2002).

3 Approach and methods

Table 1 summarises the approach taken in this study – what impacts were chosen to assess, methods used to assess them, and the sources of data. The five stages of the analysis and corresponding methods used were:

1. Deciding which impacts to measure and how (community workshops and surveys);
2. Identifying the expected yield gains in cowpea grain and cowpea fodder with the use of improved varieties and recommended management techniques (cowpea simulation model and field trials);
3. Using primary and secondary GIS data on cowpea distribution and livestock populations to define socio-economic recommendation domains and establish baseline data on production and adoption of dual-purpose cowpea;
4. Examining adoption patterns (household survey);
5. Using an economic surplus model and information from steps 2, 3 and 4 above, along with secondary data, to evaluate the potential benefits and costs of the research.

Table 1. *Impact assessment information and sources.*

What to assess	How to assess it	Sources of data
Yield gains – cowpea grain, cowpea fodder	Cowpea input-output simulation model	Field trials IITA/ILRI
Target zones (recommendation domains) for improved varieties	GIS	Secondary data from RIM, FAO.
Extent and timing of adoption	Estimates	Household survey
Value of net benefits to consumers and producers	Economic surplus model	Household survey, market survey, secondary data
Other types of impacts	Qualitative assessment	Community impact workshops

To measure the potential impact of IDPC, first an exploration of the possible impacts was needed. Because cowpea is consumed by both people and animals, improved varieties lead not only to more cowpea grain but also to more and higher-quality cowpea fodder. Depending on how they are fed to livestock, improved varieties could lead to production of more milk, meat and manure (and higher-quality manure), which if applied to millet and sorghum fields could potentially lead to more grain production, and/or more hours of traction power and improved soil fertility. This, in turn, could potentially result in higher cereals output. Of course, all of these potential 'productivity gains' depend on other management decisions (i.e. controllable factors) and a host of uncontrollable factors such as the amount and timing of rainfall and pest and disease pressures. In order to gain a better understanding of who was using cowpea, how it was being planted and used, and what types of benefits the farming households themselves perceived from the crop, community-level impact workshops were held in several villages in northern Nigeria as described in the next section (Kristjanson, Tarawali et al. 1999; Kristjanson, Place et al. 2002).

3.1 Understanding the range of benefits and impacts: community-level impact workshops

Community impact workshops were undertaken in Bichi and Minjibir villages in Kano, northern Nigeria. These villages were chosen as they were considered to represent conditions of good and poor market access, respectively, in order to capture possible differences in perceptions of the role of cowpea for villagers relatively close to wholesale markets compared to those in more isolated areas. The group discussions at the workshops elicited information on the perceived benefits of dual-purpose cowpea. These perceived benefits are realised at the plot, farm household and village/community levels, and include economic, environmental and social benefits (Table 2).

Workshop participants suggested possible indicators for improvements at the plot, household and community levels. Although most are not objectively verifiable indicators, they are nonetheless perceived as being potential ones by participants. At the plot level they included the following:

- Higher yield of cereal crop following the cowpea
- Amount/bulk of the sorghum stover remaining; the more stover, the better the soil fertility
- Colour of the soil – the darker, the more fertile
- After the rains, weeds come up faster in more fertile soils (i.e. after cowpea has been grown on them)
- Greater amounts of manure deposited on cowpea areas since grazing animals prefer cowpea residues
- Cowpea soils are loose/not compacted.

Indicators of improved well-being cited for the household level were:

- Women, men and children will be better clothed
- Improved housing conditions, such as more tin roofs, blocks made of cement rather than mud, houses painted
- Better health; fewer visits to the clinic

- Children more active/healthy.
- Women and children fatter and happier – with better skin.

Table 2. *Economic, ecological and social benefits of cowpea.*

Economic benefits	Ecological benefits	Social benefits
Cash from sale of beans Cash from sale of fodder (or savings from not having to purchase fodder)	Improvements in soil fertility from incorporation of leaves, remaining cowpea roots, manure left by grazing livestock	Neighbours can assist each other, e.g. give/sell seed from early harvest
Cash from sale of animals fed cowpea fodder	Reduction in wind/water soil erosion	Cash from cowpeas used to register a cooperative, and group members can jointly purchase inputs, get credit, etc.
Higher yields of cereal crops following cowpea; opportunity to plant a second cowpea crop during the same season	Fewer fertilisers/pesticides needed if grown in rotation with cereals	More cash available for social functions that boost community morale
Fewer medical expenses (e.g. children healthier; advised by local clinics to eat cowpeas when ill, also for reducing illness)	Soil structure improved	Cash from sale of cowpeas may be used to improve village infrastructure
Price of cowpea beans generally higher than millet or sorghum; in part because they are harvested earlier than the cereals and provide food during the 'hungry gap'		Health and well-being of all household members improved
Source of employment and income for labourers, including women, for harvesting, threshing, for example		
Savings from not having to purchase fertiliser and insecticides for cereal crop sown in rotation with cowpea		

Source: Kristjanson, Tarawali et al. 1999.

Indicators of improvements cited for the village/community level included:

- Improvements in infrastructure, such as a well with a pump and better roads
- More cash in the village economy, such as more motorcycles and more houses
- Larger market; perhaps held more often than twice a week
- More farmers who are also traders.

In addition, the percentage of cowpea sold immediately upon harvest appeared to be a useful proxy for relative household wealth or well-being since cash-strapped households are forced to sell a higher proportion of their cowpea crop immediately after harvesting. Better-off households tend to store cowpea grain for use or sale later in the season when the price is higher. Another interesting possibility that was suggested was that female farmers with access to better quantity/quality of cowpea fodder tended to manage their small ruminants more as a trading enterprise than as an emergency fall-back, implying that regular sales would be an indication of households that were faring better than those relying on emergency sales.

Quantifying these impacts is in many cases impractical. Even if possible, the costs of doing so probably outweigh the benefits. The most important benefits cited, according to the farmers' ranking, were more food and income from increased cowpea grain and fodder production. These are the benefits that were quantified in our analysis. The analysis thus underestimates the total benefits from the new technologies, but nonetheless it provides a valuable starting point. Measuring these potential yield gains in different environments required the use of a simulation model coupled with field trial data showing the 'yield gap' between the traditional and improved varieties (described in Section 3.4). First we consider the question 'Where are these impacts expected to be realised'?

3.2 Defining the recommendation domain

3.2.1 Village-survey approach and defining the recommendation domains

From the information gained from farmers in the impact workshops, and other studies of similar crop–livestock farming systems (Ehui et al. 1998; Williams et al. 1999; Inaizumi et al. 1999; Okike et al. 2001), the following hypothesis was used to select locations for a formal village-level survey:

- The varieties of cowpea grown and their importance to farming systems and livelihoods depend mainly on three socio-economic factors – human population density, livestock population density, and access to a wholesale market (for obtaining farm inputs and for sale of produce).

There are considerable livestock population fluctuations during the year in northern Nigeria. In general, during the planting season, there is a higher concentration of livestock in low-density population areas, where up to 25% of the land may be under fallow and livestock are allowed to graze. By harvest time, the grazing on these fallow plots has become exhausted and the animals are moved to more intensively farmed areas where crop residues are plentiful. The scale of these movements, and the seasonal reversal in livestock concentration, are large raising the issue of whether livestock population concentration can be used as a stratification criterion for a study that is expected to span both planting and harvesting seasons (Bourn et al. 1994). Thus we did not use livestock population density as a stratifying variable (although including it as an explanatory variable in the econometric analysis) and instead focused the study on the following four socio-economic domains (Smith, 1992; Manyong et al. 1996; Okike 1999b):

- LPLM – Low human population density (which we defined as less than 150 people per square kilometre due to the particularly high population density found throughout Nigeria) and low market access (lack of year-round road access to a wholesale market);
- LPHM – Low human population density and high market access (year-round road access to a wholesale market);
- HPLM – High human population density (> 150 people per square kilometre) and low market access;.
- HPHM – High human population density and high market access.

GIS tools were used to overlay geo-referenced spatial data on human population density and market accessibility and map each of these four zones. The human population density GIS layer used in this study was taken from Deichmann (1996). The spatial market access variable used was based on a 'market tension' concept developed by Brunner et al. (1995) which accounts for travel time to the nearest wholesale market. Market tension decreases with distance from the market, and also decreases faster off-road than on-road and faster along dirt roads than paved roads. Thus it corresponds to economic distance, defined in terms of transport cost rather than straight-line distance. The market tension indicator ranged from 1 to 10, where 10 represented easy year-round access to a wholesale market and 1 corresponded to locations with long travel times due to both distance and the condition of the roads.

Both human population density and market tension measures were derived for 1990. For each of the four socio-economic domains, 20 sample points were randomly generated using a computer programme that provided their coordinates. Thus a total of 80 points were marked on the map, and the nearest villages to these sample points were located using a GPS instrument. Group interviews were conducted in the 80 villages during a 6-week period in August–September 1999 (for details see Okike et al. 1999a; Kristjanson, Tarawali et al. 1999; Kristjanson, Place et al. 2002). Figure 2 shows the socio-economic domains, the length of growing period, roads, and the location and relative size of towns in Kano and Jigawa States.

The village-level survey addressed issues surrounding farmers' adoption decisions on IDPC. Factors affecting the intensity of adoption were estimated using a Tobit model (Kristjanson, Tarawali, et al., 2002). The dependent variable was expressed as the percentage of total village cropped area planted to improved varieties of dual-purpose cowpea. The explanatory variables related to adoption at the community level were assumed to be a function of six sets of factors: (1) the population density of the immediate area where the village is located; (2) the degree of market access; (3) the importance and relative density of livestock owned by the villagers; (4) the relative importance of cowpea compared to all other crops grown within the community; (5) the frequency of visits by the village extension officer; and (6) the relative price of improved varieties compared to traditional varieties.

The results showed that the factors with a significant and positive influence on area devoted to IDPC were socio-economic domain (i.e. LPLM, HPLM, LPHM, HPHM), importance and density of livestock, and the market price received for improved cowpea grain relative to traditional varieties. Communities located in high-population, good-market-access domains had a higher rate of adoption than the others, supporting the hypothesis that important 'drivers of change' are high population pressure coupled with good market access. Intensity of adoption was significantly and positively influenced by both the perceived importance of livestock and by the number of livestock owned (tropical livestock unit – TLU – equivalent to 250 kg live weight). Intensity of adoption was significantly and positively influenced by both the perceived importance of livestock and by the number of livestock owned (TLU density) within the village. Not surprisingly, the price of the improved cowpea grain relative to traditional varieties had a highly significant influence on the percentage area planted to IDPC. The fact that intensity of adoption is higher in the more densely populated, better market access domains, despite the fact that dual-purpose varieties and livestock are found in greater numbers and are more likely to be judged 'very important' by villagers in the other domains, highlights the opportunities for further dissemination efforts. Expanding the availability of information and improved seeds to these more remote areas is the challenge.

Extension agents are currently expected to be the major channel for disseminating new knowledge and technologies to farmers. They are also expected to influence research priorities based on feedback from farmers. The results of the village-level survey suggested that this is not happening, a situation probably not peculiar to improved cowpea varieties as it is a similar finding in related studies (e.g. Okike 1999b). Since traditional dissemination pathways do not appear to be working, national and international agricultural researchers need either to strengthen these institutions or to explore other pathways for dissemination of their research results. Such an approach is currently being pursued in the context of the 'best bet' interventions that include cowpea (Tarawali et al. 2002).

The village-level survey analysis and results highlighted some issues that could only be explored with a household-level survey. These included the need for a deeper understanding of how farmers obtain information and new technologies, and the extent to which the private sector was (or was not) reaching farmers in a manner that the public sector was apparently unable to do. It also became evident that more information was needed on within-community variation in adoption patterns. The objectives and results of the resulting household survey are given in Section 3.5. First, however, we describe how the socio-economic recommendation domains defined above were used to extrapolate survey and model results to a wider geographical area.

3.3 Extrapolation of socio-economic recommendation domains across West Africa

Section 3.2 above described how the recommendation domains were defined using information for northern Nigeria. The next step in the analysis was to extrapolate these across West Africa, and to simulate the growth and development of traditional and dual-purpose cowpeas so that productivity estimates could be obtained for the economic surplus modelling, described in Section 4.

To characterise the various recommendation domains in all the countries (Figure 3), several data sources were used. Detailed crop and livestock distribution data for West Africa are patchy, therefore we proceeded as follows. Human population totals by domain and country were calculated for all countries using the ILRI projected human population layer for 2000 from Reid et al. (2000) based on Deichmann (1996). Livestock totals by domain and country were obtained using the ILRI cattle density layer for all countries except Nigeria, for which we used the Resource Inventory Management (RIM) database (ERGO 1992). For sheep and goats, we used FAO country totals for 1999 (FAO 2000), but we weighted their distribution by human population density for the year 2000, based on the assumption that livestock (particularly small ruminants) tend to be located in the same places as people. RIM data were used for Nigeria as they were considered more accurate being derived from actual measurements using aerial surveys.

For estimating cropped area by domain and country, we used four data sources: FAO country totals for 1998 (FAO 2000), the RIM data for Nigeria, a work-in-progress mixed farming system classification for Africa (Reid et al. 2001), and the crop use intensity layers (CUI) for Mauritania, Mali, Niger and Burkina Faso from the United States Geological Survey (USGS 2001). The RIM data for Nigeria, representing percent cultivation, were converted into number of hectares per grid cell by calculating the potential maximum area based on grid cell size and multiplying that figure by percent cultivation. These results were then standardised on a country basis to match the FAO country totals for 1998.

Similarly, the CUI layers were converted into hectares per grid cell by first taking the median percent cultivation for each CUI class (unlike the RIM data, which are continuous data, the CUI data were already classed in ranges of percent cultivation). The FAO country figures were then used to standardise the cropped areas by country.

For all of the other countries where we had no sub-country information on cropped areas, we used the ILRI mixed farming system classification (Reid et al. 2001). We weighted these areas by human population density, but first it was necessary to calculate a maximum allowable human population density so that no individual grid cell could contain a greater cropped area than the total land area within that grid cell. This was carried out for each remaining country separately. The mixed farming system layer has a grid cell size of 19.78 km2, thus a maximum land area of 1,978 hectares. Using human population totals per grid cell, we derived the ratio: maximum possible human population total to total human population in mixed farming area for country, which we then multiplied by the total FAO cropped area in hectares for the country. This was then set equal to a maximum of 1,978 ha. As an example, for Cameroon, we had 7,385,200 people in mixed systems and 7,160,000 ha of cropped land. This resulted in a maximum of 2,041 people per grid cell. The human population for Cameroon was then re-classed so that no single grid cell had more than 2,041 people assigned to it. We used this re-classed human population layer to distribute the cropped areas accordingly. The results of this exercise are summarised in Table 3.

Table 3. *West Africa dry savanna zone: human and livestock populations and cropped area by socio-economic domain. Number and (percent) of West Africa dry savanna total.*

Domain	Human population, 2000	Cattle population	Sheep population	Goat population	Cropped area (ha)
LPOPLMKT	66,427,416	15,164,233	22,810,405	25,198,697	12,968,088
	(61%)	(69%)	(70%)	(76%)	(80%)
HPOPLMKT	8,965,419	1,400,972	1,910,795	1,325,154	1,074,106
	8%	(6%)	(6%)	(4%)	(7%)
LPOPHMKT	11,409,896	2,781,529	3,547,252	3,403,657	1,319,040
	(11%)	(13%)	(11%)	(10%)	(8%)
HPOPHMKT	21,588,574	2,664,540	4,501,070	3,085,198	859,375
	(20%)	(12%)	(14%)	(9%)	(5%)
Total	108,391,305	22,011,274	32,769,522	33,012,706	16,220,609

Source: Human population for the year 2000 taken from Reid et al. (2000) based on Deichmann (1996).

3.4 Using a simulation model to estimate potential yield gains in different environments: Development and testing of the CROPGRO-Cowpea model

Under the auspices of the International Consortium for Agricultural Systems Applications (ICASA), a collaborative effort was initiated between ILRI, IITA, the University of Florida and the University of Georgia. It had the long-term objective of developing a conceptual mechanism to link crop simulation models in the Decision Support System for Agrotechnology Transfer (DSSAT) software package (Jones et al. 1998, Hoogenboom, Rodriguez et al., 1999) with livestock simulation models. One of the first activities in this process was to develop a computer simulation model that could predict grain and forage yield for cowpeas as a function of weather and soil conditions and crop management inputs. The objective was to be able to predict the yield and yield variability of different cowpea varieties under different conditions so that marginal changes in productivity arising from adoption of the new dual-purpose varieties could be estimated for the impact study. The generic crop model CROPGRO (Boote et al. 1998) was taken as a starting point. To generate the data with which to adapt, calibrate and validate[1] CROPGRO-Cowpea, a substantial number of pot and field experiments were conducted in the USA and Nigeria. (More details on the field trials and experiments in West Africa and the US that provided the inputs for the CROPGRO model can be found in Appendix 1.) The following three sub-sections summarise the stages of model development, validation and application.

3.4.1 Model development and evaluation

The dual-purpose nature of the cowpea presents new challenges with respect to modelling and evaluating the productivity gains from the new varieties being studied. Traditional grain legumes are normally only grown for seed production, with the remaining biomass being left on the land. In the case of cowpea, the actual biomass, especially the leaves and stalk, can be more important than the seed it produces. As a result, some traditional local varieties and landraces have been adapted for biomass production rather than seed production (see Figure 4). Thus it was necessary to develop a new cowpea model that accounted for total biomass production rather than using crop models that concentrated only on seed production.

The cowpea model is based on the generic grain legume model CROPGRO, developed as a collaborative project between the University of Florida and the University of Georgia. CROPGRO currently includes individual models for soybean, peanut, Phaseolus bean and chickpea, as well as for tomato and Bahia grass. CROPGRO is a dynamic crop simulation model that simulates growth and development as a function of weather and soil conditions and crop management inputs. It therefore requires daily weather data, as well as a description of both the soil surface and the soil horizon layers as inputs. Crop management is defined in a separate file. CROPGRO is initiated at or prior to planting and the model simulates all processes on a daily basis. It predicts germination and emergence, first flower occurrence, as well as first pod and first seed and physiological and harvest maturity. The model also includes processes to simulate photosynthesis, respiration, and biomass partitioning to stems, leaves, roots, pods and seeds.

In addition to the carbon balance, the model also includes a detailed soil water balance that simulates potential evapotranspiration, run-off and infiltration, vertical

1 In this context, adaptation refers to structural changes that are required in the model to make it functional for simulating the growth and development of cowpea; calibration refers to the fitting of appropriate model parameters to the functional relationships within CROPGRO-Cowpea; and validation refers to the testing of the model, using independent data sets not used in its adaptation or calibration, where real and modelled output are compared to assess the performance of the model.

water flow between soil layers, root water uptake and transpiration (Ritchie 1998). Drought stress is calculated when the potential transpirational water demand is larger than the available water uptake by the roots. Drought and related stress factors then impact the individual growth and developmental processes at various levels, depending on the sensitivity of these individual processes to stress (Hunt and Boote 1998).

The nitrogen balance includes separate processes to calculate nitrogen fixation and uptake by the root system, as well as nitrogen mobilisation between the individual plant components. In addition, various soil processes are simulated, such as nitrogen mineralisation and immobilisation, nitrification and denitrification, nitrate and urea movement, and ammonia volatilisation (Godwin and Singh 1998).

Experimental data, collected in field experiments conducted in 1998 under controlled conditions in the Georgia Envirotron at the University of Georgia, were used for initial model calibration. The data for cultivar TVu 3644, originally from Zaire, with a phenology similar to Nigerian cultivars, were used for comparison with simulated data by the CROPGRO-Cowpea model. This was the major cultivar selected because of its similarities to the fodder types grown in West Africa. Figure 5 shows a comparison of simulated and observed vegetative growth stages for the Nigerian cultivar grown at three different temperature regimes in the Georgia Envirotron. The simulated V-stages show an excellent agreement with the observed data. Similar results were obtained for the growth analysis data collected under field conditions. Leaf area index (LAI, Figure 6), leaf and stem weight (Figure 7) and total above-ground biomass and pod weight (Figure 8) all showed excellent agreement between simulated and observed data. It should be noted that these data were used for initial model development and calibration, so a good initial agreement between field results and model performance would be expected.

The growth analysis and developmental data, collected in the 1999 experiment conducted at the IITA station in Minjibir, Kano, were also used for model evaluation (validation) in order to determine the parameters that define the characteristics for cultivars grown in West Africa. Stem and leaf weight data over time for the cultivars IT86D-719 (a grain type), Kanannado (a local forage type), and IT90K-277-2 (a dual-purpose variety based on improvements to the local forage variety Kanannado) are shown in Figure 9. Cultivar IT86D-719 shows the shortest growth duration, followed by IT90K-277-2 and Kanannado. Simulated data compared fairly well to observed data, except in the case of Kanannado, for which the model slightly under-predicted total stem weight and growth duration. Above-ground biomass and pod weight gave similar results (Figure 10). These growth analyses data clearly show that there is a significant difference in growth habit between the traditional forage-type cowpeas (as expressed by Kanannado), and the grain or dual-purpose cultivars.

3.4.2 Crop model application

Table 4 shows the input data required to run the CROPGRO-Cowpea model. The files required for input and the output files produced are shown in Table 5. As a component of the DSSAT version 3.5 (Tsuji et al. 1994; Hoogenboom, Wilkens and Tsuji 1999), the CROPGRO-Cowpea model is part of an integrated software package, meaning that a wide variety of soil, weather and crop management databases are available for application of the model. Details of the DSSAT software package can be found at the ICASA web site (http://www.icasanet.org). In addition, there are a wide range of analysis programs, include seasonal, sequence and spatial analysis programs, that can be used to assess model outputs (Thornton and Hoogenboom 1994; Thornton et al. 1995, 1997). As an example of the type of information that the model can produce, Figure 11 shows simulated cumulative probability functions of biomass yield for local and improved dual-purpose cowpea varieties at two locations. At the first location (Treatment 12), the improved dual-purpose variety yields more over the entire probability interval, while at the second (Treatment 80) the local variety out-yields the improved dual-purpose variety in about one year in four. Note also that at this location the model indicates that the cowpea crop will fail about one year in 20 as a result of adverse weather conditions.

Table 4. *The minimum data set for operation of CROPGRO-Cowpea*

1. Site
- Latitude and longitude; elevation; average annual temperature; average annual amplitude in temperature
- Slope and aspect; major obstruction to the sun (e.g. nearby mountain); drainage (type, spacing and depth); surface stones (coverage and size)

2. Weather
- Daily global solar radiation, maximum and minimum temperatures, precipitation

3. Soils
- Classification using the local system and (to family level) the USDA-SCS taxonomic system
- Basic profile characteristics by soil layer: in situ water release curve characteristics (saturated, drained upper limit, lower limit); bulk density, organic carbon; pH; root growth factor; drainage coefficient

4. Soil analysis
- Surface layer(s) measurements of bulk density, pH, organic carbon, organic nitrogen, P and K

5. Initial Conditions
- Previous crop, root and nodule amounts; numbers and effectiveness of rhizobia
- Water, ammonium and nitrate by soil layer

6. Management
- Cultivar name and type, and cultivar characteristics
- Planting date, depth and method; row spacing and direction; plant population
- Irrigation and water management, dates, methods and amounts or depths
- Fertiliser (inorganic) and inoculant applications
- Residue (organic fertiliser) applications (material, depth of incorporation, amount and nutrient concentrations)
- Chemical (e.g. pesticide) applications (material, amount)
- Tillage
- Environment (aerial) adjustments
- Harvest schedule

Source: Hunt and Boote 1998.

Table 5. *Files used for the storage and transfer of data relevant to model operation, calibration and evaluation using the CROPGRO-Cowpea model*

Reference Name	File name(s) (Example)	Description
MODEL INPUT FILES		
Experimental details		
FILEX	UFGA8201.MZX	Experimental details for a specific (e.g. UFGA8201MZ) study/model run: field conditions, crop management.
Weather and soil		
FILEW	UFGA8201.WTH	Weather data, daily, for a specific (e.g. UFGA) station, or for a specific station and time period (e.g. for one year).
FILES	SOIL.SOL	Soil profile data for a group of experimental sites in general UF.SOL (SOIL.SOL) or for a specific institute (e.g. UF.SOL).
Crop and Cultivar		
FILEC	MZCER960.CUL	Cultivar-specific coefficients for a particular model and crop species, e.g. maize for the 'CER' model, version 96 (i.e. released in 1996).
MODEL OUTPUT FILES		
OUTO	OVERVIEW.OUT	Overview of inputs and major crop and soil output variables.
OUTS	SUMMARY.OUT	Summary information: crop and soil input and output variables, one line for each crop cycle or model run
		Detailed time-sequence information on:
OUTG	GROWTH.OUT	Growth
OUTW	WATER.OUT	Water balance
OUTN	NITROGEN.OUT	Nitrogen balance
SYSTEM PERFORMANCE FILES		
FILEA	UFGA8201.MZA	Average values of performance data for a specific (e.g. UFGA8201MZ) experiment. Used for comparison with summary model results.
FILET	UFGA8201.MZT	Time-course data (averages) for a specific (e.g. UFGA8201MZ) experiment. Used for graphical comparison of measured and simulated time-course results.

Source: Hunt and Boote 1998.

3.4.3 Simulating cowpea production by recommendation domain

The next task was to estimate cowpea production changes as a result of adoption of improved dual-purpose varieties compared with traditional varieties in each of the recommendation domains across West Africa. To do this, it was necessary to assemble soil and weather data as input to CROPGRO-Cowpea.

For soils data, we used the FAO digital soils map of the world (FAO 1974; 1995). The part of the map covering the area of the recommendation domains is shown in Figure 12. The ILRI databases now contain soil profiles, in DSSAT format, that can be applied to all of the agricultural soils in all of the FAO mapping units (Jones and Thornton 2001). This was done by classifying each soil type as not suitable, marginally suitable or highly suitable for rain-fed agriculture (FAO 1978; Fischer et al. 2000). In the case of those soils that were classified as marginally or highly suitable, the WISE soils database (Batjes 1995) was sampled to obtain a matching soil type - if possible, from the same country; if not, then from the same continent; and failing that, from somewhere in the world. Soil water holding capacities of each soil profile were estimated form soil texture using pedotransfer functions in a computer program written by Nijbroek (2000).

Weather databases for West Africa are as patchy as crop and livestock distribution data in general. We wanted to be able to assess changes in yield variability as well as yield levels, so we required 20 years of daily data for each location. To do this, we used MarkSim, a program that can generate characteristic daily data for any site in Latin America and Africa on a 10-minute grid size (Jones and Thornton 2000).

Based on the number of soil mapping units across West Africa and the number of 10-minute weather grid boxes, we found nearly 10,000 unique combinations of soil and weather conditions in the complete recommendation domain. To make the resulting computing task less complex, we randomly sampled points from across the region at an overall rate of approximately 10%, ensuring that each recommendation domain was sampled in the process (the rate of sampling in the very small recommendation domains went up to about 30%). The location of these points is shown in Figure 13.

To assemble model input files, we proceeded as follows. Each randomly drawn sampling point corresponded to one 30-minute grid box of the climate surfaces in MarkSim (i.e. at the equator, a square with 18-km sides, approximately, within which weather conditions are assumed to be homogeneous). This corresponds to four grid cells of the version of the FAO soils map that was used. A weighted mapping unit was then constructed for the 30-minute grid cell size, and to produce a set of 'treatments' that the model would be required to run through. A total of 1859 distinct combinations of soil type and weather conditions were simulated (Table 6). For each sampling point, MarkSim was used to generate 30 years' of characteristic daily data that could be run directly with CROPGRO-Cowpea by running through each of the treatments shown.

Once the simulations had been completed, the results were post-processed to calculate weighted average yields for each sampling point, and then weighted again to derive a single set of outputs for each recommendation domain. The results are tabulated in Table

Table 6. *Soil and weather combinations that define the 1859 treatments for running one scenario with CROPGRO-Cowpea.*

Longitude ºW	Latitude ºE	Elevation ºN	Soil type m	% cover	Weather ID	RD Number
-8.360	14.633	274	FAQL000001	70	1001	1
-8.360	14.633	274	FAQC000001	30	1001	1
-12.640	15.553	91	FARE000001	90	1002	1
14.240	12.273	274	FAVP000001	30	1004	1
5.680	13.433	335	FAJE000001	60	1005	1
5.680	13.433	335	FAGH000001	30	1005	1
-4.760	13.673	274	FALF000001	60	1006	1
-4.760	13.673	274	FALG000001	20	1006	1
-2.720	13.993	274	FARE000001	50	1007	1
-2.720	13.993	274	FALF000001	20	1007	1
-2.720	13.993	274	FAQL000001	20	1007	1
-10.200	15.353	182	FAQL000001	70	1008	1
-10.200	15.353	182	FAQC000001	30	1008	1
.960	13.753	274	FALF000001	70	1009	1
.960	13.753	274	FARE000001	30	1009	1
-6.960	14.153	304	FALF000001	60	1010	1
-6.960	14.153	304	FARE000001	20	1010	1
-.080	13.753	365	FARE000001	70	1011	1
-.080	13.753	365	FAQL000001	30	1011	1
7.400	9.313	609	FALF000001	50	1931	16
7.400	9.313	609	FALP000001	30	1931	16
7.400	9.313	609	FAGE000001	10	1931	16
9.040	9.833	1219	FALF000001	30	1932	16
9.040	9.833	1219	FARE000001	30	1932	16
7.360	9.273	609	FALF000001	50	1933	16
7.360	9.273	609	FALP000001	30	1933	16
7.360	9.273	609	FAGE000001	10	1933	16
6.440	9.393	213	FALP000001	70	1934	16
6.440	9.393	213	FALF000001	30	1934	16
8.040	9.433	822	FALF000001	50	1935	16
8.040	9.433	822	FALP000001	30	1935	16
8.040	9.433	822	FAGE000001	10	1935	16

Where: RD = recommendation domain.

Soil types: The 3rd and 4th characters represent the FAO unit (e.g. Ql = Luvic Arenosol, Qc = Cambic Arenosol, Re = Eutric Regosol etc.).

Weather site 1001 (corresponding to one sample point in Figure 13 is in recommendation domain number 1 (see legend of Figure 3) and consists of 70% Ql and 30% Qc, both of which are suitable for cowpeas. CROPGRO-Cowpea is then run for two treatments for this point, using the same weather data, and the resultant yields are weighted by 0.7 and 0.3, respectively, to give a mean yield for that sample point.

7. It is important to note that the model yields are constrained by weather and soil conditions, but in the absence of weeds, pests, diseases, etc. Thus it was felt that the yields reported in Table 7 would overestimate impacts, and should be discounted by some factor, similar to that typically applied to research station yields in comparison with on-farm yields. This factor was not easy to estimate since it will vary considerably, but we chose a 'yield discount' factor of 3. We felt that discounting the model results would capture the differences between on-farm yields and on-station (ideal conditions) yields, while still preserving the differences between recommendation domains in terms of soil and climatic conditions. Thus the old and new grain and fodder yields given in Table 7 were divided by a factor of 3, and it is these figures that were then used in the economic surplus modelling described below.

Table 7. *Results of CROPGRO-Cowpea simulations, weighted for the four recommendation domains.*

Population density	Market access	Area %	Grain yield (t/ha)			Fodder yield (t/ha)		
			New	Old	New/Old	New	Old	New/Old
L	L	90	.854	.516	1.66	1.16	1.51	0.77
L	H	6	.821	.507	1.62	1.10	1.38	0.80
H	L	2	.892	.566	1.58	1.26	1.67	0.75
H	H	2	.820	.484	1.70	1.15	1.45	0.79

Where: New = improved variety; Old = traditional variety

As an indication of the spatial and temporal variability of cowpea yields, Figure 14 shows average simulated cowpea biomass yield for the local variety (Thiessen polygons were used to interpolate the point data corresponding to Figure 13). Figure 15 shows the coefficient of variation of biomass yield for all recommendation domains. As might be expected, there is a tendency for higher and less variable yields to be associated with the wetter areas in the south of the region. This would suggest that rainfall is a limiting factor for potential cowpea production only in the drier, northern areas of the region.

3.5 Household survey approach and results

The final pieces of information required for the economic surplus model and quantification of the benefits of IDPC, concern our ability to predict who will take up the new technology, and how quickly (i.e. adoption lag and ceiling level of adoption). In order to estimate potential adoption ceiling rates and lags (along with a better understanding of the adoption process itself, as mentioned earlier), a household-level survey was undertaken (Kristjanson, Okike et al. 2001). The objectives of the survey were to:

- Examine household characteristics affecting adoption of improved dual-purpose varieties;

- Identify the various potential impacts from use of improved dual-purpose cowpea varieties, including impact on food security, income, assets and household welfare;
- Establish baseline data on area planted and production levels of dual-purpose cowpea varieties for future ex post impact assessments that will measure the actual adoption of new varieties developed through this research.

For the household-level survey, it was necessary to have a sample with enough IDPC adopters to be able to learn something about the determinants of adoption and the differences between adopting and non-adopting households. Seventeen out of the 80 villages surveyed in the original village-level survey had adopters, i.e. improved cowpea varieties were present. From this sample of 17 'improved cowpea adopting villages', 4 villages were selected by stratified random sampling for the detailed household-level survey, 1 village representing each of the four socio-economic domains.

Both women and men were interviewed, although it was necessary to do this in two separate surveys due to cultural constraints. The sampling frame for the main household survey consisted of all cowpea-farming households in the four selected locations regardless of their status as adopters, non-adopters or those who had abandoned adoption of improved varieties. The wives of improved cowpea farmers constituted the sampling frame for the gender aspects survey. A list of all households in each of the communities studied was obtained from the village head, and a sample of 120 cowpea-farming households and 40 wives of such household heads randomly selected. A total of 484 male household heads (although only 462 were included in the final analysis of this data) and 298 housewives were interviewed.

As part of the determination of household characteristics, a wealth-ranking exercise was undertaken in each community. Four individuals who knew every member of the community volunteered to rank the 120 selected households in each village. Three wealth ranks were preferred, so the people that they ranked as rich were scored 3, the middle class scored 2, and the poor scored 1. The four scores were then averaged for each household, resulting in the following classification: average score of <1.5 = poor, 1.5–2.5 = middle class, and >2.5 = rich.

Fifty percent of the households surveyed were not using IDPC varieties, 41% were, and 9% had tried them but were no longer using them (Table 8). Table 8 also summarises what adopting households had to say about sources of information and improved seeds. Over one-half of the adopters found out about the new varieties from an extension agent, 22% from a neighbour, and 14% from a trader. The initial source of the improved seed was an extension agent for 59%, a neighbour (25%), a trader (8%), and a researcher (5%).

Farmers gave their views on the advantages and disadvantages of IDPC and indicators of positive impact, as well as reasons that they had not tried planting IDPC (Table 9). Fifty-eight of the sampled households had heard about IDPC varieties (keeping in mind that the villages were chosen purposively to include adopters), and higher grain yield was the overwhelming advantage over local varieties, cited by 69% of respondents.

Table 8. *Characteristics of farm households' adoption of improved dual-purpose cowpea (IDPC) varieties.*

	Percent of farmers
Percentage of sample farmers (N = 462) that have heard about IDPC varieties	58
Source of knowledge about IDPC varieties:	
Neighbouring farm	22
Researcher	7
Field day	2
Trader	14
Extension agent	54
Neighbouring village	1
Initial source of IDPC planted by adopting farmers:	
Neighbouring farm	25
Researcher	5
Field day	1
Trader	8
Extension agent	59
Radio	2
Percentage distribution of farmers by adoption of IDPC:	
Percentage of adopting farmers	41
Percentage of non-adopting farmers	50
Percentage of farmers that have abandoned adoption	9
Percentage distribution of farmers by participatory wealth ranking:	
Percentage of poor farmers	27
Percentage of middle-class farmers	60
Percentage of rich farmers	13
IDPC varieties have advantages over local varieties	55
Reasons?	
Higher grain yield	69
Higher fodder yield	2
Higher cereal yield following IDPC	4
Lower operational costs	4
Two crops per year as against one for local varieties made possible	
Early maturing	19
IDPC varieties have disadvantages compared to local varieties	56
Reasons?	
Requires insecticide spray	88
Difficult to obtain pure seeds	6
Capital intensive	4
Labour intensive	1
Intolerant to water logging	
Requires fertilisers initially	1

Table 9. *Farmers' views on improved dual-purpose cowpea (IDPC) varieties.*

	Percent of farmers
Relative to last planting season, my IDPC area has increased this season	44
Reasons?	
More income	54
High quality food for household	31
Source of employment	9
Fodder for livestock	1
Soil enrichment	1
Improved management practices	1
Other reasons	3
Relative to last planting season, my IDPC area has decreased this season	2
Reasons?	
Land shortage	58
Others	42
Impact of IDPC on households is positive	54
Indicators of positive impact on household:	
Higher household income	72
Healthier/happier household	12
Active children	1
Household better clothed	9
More livestock	2
Improved housing	2
Others	2
Impact of IDPC on community is positive	54
Indicators of positive impact on community:	
Better roads	1
Pumps on communal wells	1
More houses in community	23
More cycles	36
More traders/visitors/commerce	30
More marriages	4
More employment	3
Never tried planting IDPC varieties at all	37
Reasons?	
Never heard of them	4
Too risky to plant	29
No access to seeds	45
Local cowpea varieties meet my needs	3
Land is underutilised with improved varieties	2
Lack of facilities for spraying	10
Other reasons	7

This was followed by the early maturing characteristic of the new varieties (19%), higher cereal yield (4%), lower operational costs (4%), and higher fodder yield (2%). The greatest disadvantage of IDPC varieties cited was the perception that they require insecticide spray (88% of respondents), followed by the difficulty of obtaining pure seeds (6%). The most common household impacts given were higher household income (72%) and a healthier, happier household (12%). Positive community impacts cited included more bicycles, more traders/visitors, commerce, and more houses in the village. Reasons given for not trying IDPC varieties included no access to seeds (45%), they were too risky to plant (29%), and lack of facilities for spraying (10%).

Differences between adopting and non-adopting households with respect to several variables that serve as proxies for, or indicators of, household income/welfare, assets/wealth, and food security were examined using analysis of variance (Table 10). These variables included:

- Income or welfare proxies (flows): Gross farm revenues (from crops and livestock); gross revenue from sale of cowpea grains, gross revenue from sale of cowpea fodder; gross revenue from sale of non-cowpea crops, percentage of non-farm income; number of wives in household.
- Food security proxies: Number of months household is typically deficit in cereals or cowpea grains; number of months household has surplus cowpea grains.
- Asset proxies (stocks): Livestock holdings (TLU); percentage of children educated up to secondary level; whether the house is cemented, has a zinc roof or is painted; if the household head owns a bicycle.

The results of the comparison between adopting households and non-adopting households suggest that adopters have a higher income and agricultural earnings. All of the agricultural-related variables showed significant differences in the means between adopters and non-adopters (at the 1% level). Interestingly, the amount of non-farm income did not vary significantly between adopters and non-adopters. Adopters also have more wives than non-adopters, an indicator of higher status and wealth for those households, although not necessarily a measure of improved household well-being. IDPC-adopting households were in deficit in both cereals and cowpea grains for a statistically significant shorter period of time each year, suggesting this technology contributes to enhanced food security for adopting households. Herd size (TLU) was larger for adopters than non-adopters. However, with respect to other asset indicators (cement house, zinc roof, etc.), no significant differences in asset levels between adopters and non-adopters were seen (which agreed with what community members said during the wealth ranking exercise – namely, that wealth indicators such as zinc roofs, for example, were unimportant compared to the number of livestock owned by a household).

Table 10. *Analysis of variance comparing household socio-economic characteristics of adopters and non-adopters of improved dual-purpose cowpea varieties.*

Variable and level of statistical difference between groups	Adopters N = 190 Value (s.e.)	Non-adopters N = 229 Value (s.e.)	Stopped N = 43 Value (s.e.)	All N = 462 Value (s.e.)
No. of TLU owned***	3.1 (0.28)	2.2 (0.21)	1.9 (0.32)	2.7 (0.17)
Gross farm revenue (crops + livestock) ('000 Naira)***	175.8 (28.7)	66.7 (18.1)	64.8 (10.3)	125.5 (17.1)
Gross revenue from cowpea grains ('000 Naira)***	33.6 (6.8)	6.7 (0.8)	5.2 (1.0)	21.1 (3.8)
Revenue from sale of cowpea fodder ('000 Naira)***	27.0 (5.7)	4.1 (0.6)	3.1 (0.8)	16.4 (3.1)
Gross revenue from non-cowpea crops ('000 Naira)***	121.9 (27.1)	25.0 (1.7)	42.1 (7.2)	79.0 (14.8)
Percentage of non-farm income	44.4 (1.4)	47.6 (1.7)	50.8 (3.3)	46.2 (1.0)
Household deficit in cereals (months)***	1.6 (0.15)	2.5 (0.31)	2.2 (0.43)	2.0 (0.15)
Household deficit in cowpea grains (months)***	3.2 (0.24)	5.8 (0.32)	4.8 (0.71)	4.3 (0.20)
Household has surplus cowpea grains (months)	0.4 (0.07)	0.2 (0.10)	0.3 (0.3)	0.3 (0.06)
No. of wives in household**	1.9 (0.06)	1.7 (0.06)	1.8 (0.12)	1.8 (0.04)
Percentage of children in household educated up to secondary level**	55.6 (2.3)	65.4 (2.6)	62.1 (4.6)	59.8 (1.6)
House cemented (%)	23	10	4	37
House has zinc roof (%)	32	20	6	58
House is painted (%)	9	2	2	13
Household head owns a bicycle (%)	24	11	3	38

***1% level of significance (LOS), **5% LOS and *10% LOS.

A probit model was used to examine the determinants of intensity of adoption, where the dependent variable was percentage of total cowpea area devoted to improved dual-purpose varieties. Independent variables were farm size; household size; number of plots; average distance of plots from the village; labour use (hired and household); animal-traction use; amount of fertiliser, manure and insecticides used; use of credit; group membership; number of varieties planted; herd size (TLUs); socio-economic domain; and wealth rank.

The results of the probit analysis supported the findings of the village-level survey with respect to socio-economic domain: the higher the population density and better the market access, the higher the intensity of adoption of IDPC. Farm size was a significant factor at the household level, and negatively related to the percentage of cowpea land planted to IDPC, implying that smaller farms are also benefiting from the new varieties (since typically farms are split to pass on land to sons, smaller farm size is also associated with younger farmers who may be more willing to try new interventions). Those households planting many varieties of cowpea had higher percentages of their land down to IDPC, along with those that were members of a group. Households with larger herds had a higher intensity of adoption of IDPC, as expected, but interestingly the amount of labour available to the household (household plus hired) and household size were not significant factors explaining intensity of adoption. Labour is often cited as a factor limiting uptake of new technologies, but our finding suggests that for most households lack of labour is not a problem in adopting the improved varieties. Other factors that did not significantly influence uptake of IDPC were the amount of credit and the wealth rank of the household, which seems to suggest that it is not only the wealthiest households that find themselves in a position to be able to try the new varieties.

As described in more detail below, the findings from the household survey regarding adoption of IDPC were used to estimate the adoption parameters used in the economic surplus model.

4 Measuring the potential economic benefits of improved dual-purpose cowpea using an economic surplus model

An economic surplus model (Alston et al. 1995) was developed to evaluate the benefits from the research as identified above. A partial-equilibrium, comparative static model of a closed economy was used in the analysis. Assuming a closed economy implies that the adoption of a cost-reducing or yield-enhancing technology increases the supply of a commodity such as cowpea grain or fodder. This implies that there is little or no international trade in cowpea, so the increase in supply reduces both the cost of cowpea to consumers and the price to producers. The simple case of linear supply and demand curves with parallel shifts was chosen. A review of studies of research benefits by Alston et al. (1995) revealed that most have used these assumptions. Alston and Wohlgenant (1990) argued that when a parallel shift is used (as suggested by Rose 1980), the functional form is largely irrelevant, and that a linear model provides a good approximation to the true (unknown) functional form of supply and demand. This model is described in considerable detail elsewhere and is not repeated here (Alston et al. 1995; Kristjanson, Swallow et al. 1999).

In brief, adoption of IDPC is assumed to shift the supply curve of the product (such as cowpea grain, cowpea fodder) upwards, resulting in a new equilibrium price and quantity of the grain and fodder marketed. Gross annual research benefits are measured by the area between the two supply curves and beneath the demand curve. This area represents the total increase in economic welfare (change in total surplus), and comprises both the changes in producer and consumer surplus resulting from the shift in supply. Consumers are better off because they consume more at a lower price. Supply increases also lower the per-unit cost of production for producers. And although producers receive a lower price for their crop, they are able to sell more, so their benefits increase (unless supply is perfectly elastic or demand is perfectly inelastic, in which case their producer surplus remains the same). The change in total surplus can be thought of as the *maximum* potential benefits to IDPC; these would be *actual* benefits if the research was completely successful and the results fully adopted.

The results of the cowpea simulation model (see Table 7) provided the basis for the estimate of the gross proportionate increase in production in cowpea grain and cowpea fodder that results from use of the new variety. As discussed in Section 3.4.2, the predicted grain and fodder yields from the simulation model, while capturing variability in yields due to trends in rainfall and variation in soils, do not account for the less predictable realities farmers face in West Africa (e.g. pests, diseases, labour bottlenecks), so a 'yield discount' factor of 3 was applied to the simulated yields shown in Table 7. These then represented the estimated productivity gains from IDPC, and were then converted to gross proportional reductions in cost per tonne of output by dividing the estimated productivity gain by the elasticity of supply. This is a gross reduction in output cost because the change in input costs associated with the introduction of the new variety also has to be considered. In the case of improved dual-purpose cowpea, these include the cost of the seeds and added costs of insecticide spray that is recommended for optimal productivity gains in grain yield. (One of the advantages of the dual-purpose varieties is that if farmers do not apply insecticides grain yield falls, but less so than grain-type varieties and fodder yield is largely unaffected). The costs were estimated using the average annual cost of insecticides and seeds in several of the surveyed villages. The net proportionate change in marginal cost per tonne of output was thus derived by subtracting the variable input cost changes associated with the use of the new varieties.

The productivity gains for each of the products (cowpea grain and cowpea fodder) were valued using local market prices (from the household and market surveys)[2] for each recommendation domain and the benefits added up across domains and then compared to the estimated research and extension costs. Total research costs for the scientific and dissemination effort to date were estimated by the IITA, ILRI and NARS cowpea research team and are included for 2000. Probable extension expenditures necessary for dissemination of IDPC across the West Africa dry savannah zone were estimated from the Nigerian experience and reflected the fact that the dissemination of improved varieties is limited in other countries and considerable information dissemination efforts (not to mention seed-multiplication initiatives) will be needed. The results of the benefit-cost analysis are presented in Section 5.

The initial quantity of each product came from the GIS analysis that estimated the total amount of cropped area in each recommendation domain multiplied by the average proportion of cowpea area in total cropped area for each domain from the household survey (Table 11). The predicted productivity gains were applied to these starting quantities. Prices and elasticities came from the household survey and from secondary data sources.

Table 11. *Cropped area devoted to cowpea from household survey (n = 462 households).*

	Percent cropped area under cowpea	Cropped area estimate for West African dry savannahs (ha)*
LPLM	30	12,968,088
LPHM	33	1,319,040
HPLM	29	1,074,106
HPHM	30	859,375

* ILRI GIS estimates from various data sources (see Table 3).

2 If indeed fodder is becoming more valuable than grain with the growth in demand for livestock products (Delgado et al. 1999), we should see the ratio of the price of cowpea grain to fodder falling over time. Unfortunately, we do not yet have a sufficient length of time series price data either on cowpea grain or fodder within the same market to test this hypothesis, but these price data continue to be gathered for future analyses.

4.1 Adoption parameters

The standard supply-and-demand diagram demonstrating shifts in the supply curve due to adoption of a new technology represents research benefits for one product for one year. A successful research investment will yield benefits over a number of years. As the level of adoption increases there will be further shifts in the supply curve, and corresponding changes in benefits. This adoption process was assumed to follow a typical S-shaped curve approximated by a discrete time distribution (Alston et al. 1995). In the analysis, we used the inverse of the triangular probability density function, which is well suited to this task.

Thus, the parameters that have to be chosen are the ceiling level of adoption and the adoption lag, i.e. the length of time until maximum adoption is expected to occur. Previous ILRI ex post impact studies suggest that the adoption period for agricultural interventions in sub-Saharan Africa is long – at least 15–20 years (Elbasha et al. 1999). Thus, a 20-year time horizon was chosen for this analysis.

The results of the household survey were used to extrapolate and estimate ceiling adoption rates that can be expected across the entire West Africa dry savannah region. Since the household survey was undertaken in an area where adoption is already occurring, and little or no adoption has yet occurred elsewhere, the percentage of households that have already adopted improved dual-purpose cowpea in the northern Nigeria sample was assumed, perhaps conservatively, to be the *ceiling* rate of adoption. In other words, the adoption rate ceiling for 2019 was assumed to be the observed ratio of improved dual-purpose cowpea area to total cowpea area for the surveyed households for each domain (LPLM, 0.29; LPHM, 0.35; HPLM, 0.05; and HPHM, 0.43). Assuming an S-shaped adoption curve over the 20-year period, we then worked backwards to a zero adoption rate in 2000 for the entire region. We felt that this approach was appropriate, even though adoption in 2000 was above zero, since it will tend to underestimate (rather than overestimate) total adoption.

The benefits and costs of the research were arrayed on a yearly basis over a 20-year period, and a discount rate of 5% applied in order to calculate the net present value (NPV) of IDPC research and extension efforts: the sum of total discounted returns minus total discounted costs. A positive NPV implies the research and extension efforts are profitable. The internal rate of return (IRR), or the discount rate at which the NPV is zero, was also calculated and can be compared to the opportunity cost of funds. The benefit–cost ratio, or total discounted returns divided by total discounted costs, was also calculated.

Since the precise values of each of the input values (or, for that matter, their probable distribution) are unknown, sensitivity analyses were conducted on selected variables to determine the impact on the outcomes if alternative starting values were chosen.

5 Results: Assessing potential impact

A spreadsheet model was developed to calculate the change in economic surplus (benefits–costs) for each product (cowpea grain and cowpea fodder) and domain. This model is available from the authors on request. A detailed list of the assumptions and input data sources can be found in Appendix 2. Table 12 displays the total benefits (i.e. producer and consumer surpluses) for all domains by product against the estimated research and extension (R&E) costs, and shows the predicted returns to the R&E investment in improved dual-purpose cowpea (i.e. NPV, or discounted value of the stream of net benefits expected over the next 20 years, the IRR on the investment, and the benefit:cost ratio).

Table 12. *Total benefits and costs for grain and fodder, all domains: dry savanna zone of West Africa (US$ million).*

	Total Benefits: Grain				Net Benefits: Fodder						
Year	LPLM	LPHM	HPLM	HPHM	LPLM	LPHM	HPLM	HPHM	Benefits All domains	R&E Costs	change Economic surplus
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5	-5.00
2001	0.70	0.13	0.01	0.07	-0.20	-0.02	0.00	-0.02	0.67	3	-2.33
2002	2.87	0.52	0.04	0.29	-0.80	-0.10	-0.01	-0.07	2.74	3	-0.26
2003	6.48	1.16	0.09	0.65	-1.81	-0.22	-0.03	-0.17	6.16	2	4.16
2004	11.52	2.05	0.15	1.15	-3.23	-0.39	-0.05	-0.30	10.91	2	8.91
2005	17.98	3.18	0.23	1.80	-5.07	-0.61	-0.07	-0.47	16.96	1	15.96
2006	25.86	4.53	0.34	2.59	-7.35	-0.88	-0.11	-0.68	24.29	1	23.29
2007	35.10	6.10	0.45	3.51	-10.06	-1.21	-0.15	-0.93	32.82	1	31.82
2008	45.71	7.89	0.59	4.58	-13.22	-1.59	-0.19	-1.22	42.54	1	41.54
2009	57.68	9.88	0.74	5.78	-16.84	-2.02	-0.25	-1.56	53.41	1	52.41
2010	70.64	12.00	0.91	7.08	-20.83	-2.50	-0.31	-1.93	65.07		65.07
2011	82.59	13.93	1.06	8.28	-24.59	-2.95	-0.36	-2.27	75.68		75.68
2012	93.20	15.60	1.19	9.35	-28.00	-3.36	-0.41	-2.59	84.97		84.97
2013	102.49	17.03	1.30	10.29	-31.07	-3.73	-0.46	-2.87	92.98		92.98
2014	110.48	18.22	1.40	11.10	-33.78	-4.05	-0.50	-3.12	99.75		99.75
2015	117.19	19.20	1.48	11.78	-36.13	-4.33	-0.53	-3.34	105.31		105.31
2016	122.62	19.95	1.55	12.34	-38.11	-4.57	-0.56	-3.52	109.70		109.70
2017	126.79	20.50	1.59	12.77	-39.71	-4.76	-0.58	-3.67	112.93		112.93
2018	129.71	20.84	1.62	13.08	-40.93	-4.90	-0.60	-3.78	115.05		115.05
2019	131.39	20.99	1.64	13.26	-41.75	-4.99	-0.61	-3.86	116.06		116.06
2020	131.82	20.94	1.64	13.32	-42.18	-5.04	-0.62	-3.89	115.99		115.99
Sum	1422.32	234.65	18.02	143.07	-435.67	-52.23	-6.40	-40.27	1283.49	20	1263.49

NPV US$ 606.4 million IRR 71% B:C Ratio 63.2

Net economic benefits, as given in Table 12, are negative during the first three years of the analysis since the bulk of the research expenditure has already been made and is included in the R&E costs estimate for the first year. The adoption period is assumed to begin in the first year (even though some adoption has already occurred), and the annual increase in benefits quickly offsets the ongoing research costs plus the extension costs assumed to be incurred to diffuse the seeds more widely. In the year 2018, benefits begin to level off as the upper ceiling on diffusion is reached.

The rate of return to the R&E investment on dual-purpose cowpea in the West African dry savannah zone is projected to be very high, with an IRR of 71%. The IRR criterion is generally to accept all projects that have an IRR greater or equal to the opportunity cost of capital, usually expressed as the interest rate. Thus this research investment passes the IRR test, surpassing even high estimated opportunity costs to capital in the region due to market failures, for example. While these projected returns are on the high side, they are not unreasonable. For example, a recent analysis of the rate of return to improved rice varieties in Senegal projected even higher returns, with an IRR of 121% (Fisher et al. 2001). The Fisher study argued, and we would concur, that a key determinant of these predicted high returns is the low cost and rapid success of the research programme, and we would add to this the relative ease of adoption of improved varieties that do not require significant changes in farmers' behaviour patterns. The NPV of the research and extension investment in IDPC is predicted to be US$606 million, with a benefit:cost ratio of 63. Given the uncertainty underlying some of the key parameters in this type of analysis, a sensitivity analysis was undertaken to examine the relative robustness of these results in the face of the various assumptions made.

5.1 Sensitivity analysis

Since the observed farm-level yields were considerably lower than the yields predicted by the model (which takes into account rainfall and soil variability, but assumes no other constraints), it was clear that we had to apply some kind of a discount factor. Because the average difference in yields across domains was approximately three-fold between survey and model results, for the baseline analysis we divided the yields predicted by the model by three. However, the exact yield discount factor to be applied is debatable as it will vary considerably from farmer to farmer. Over time, this gap should close as farmers become more familiar with the new seeds and suggested management techniques that accompany them. A sensitivity analysis was thus carried out to study the implications for the results when the yield discount factor was increased from 3 to 4, and decreased from 3 to 2 (Table 13). An increase in the yield gap from a factor of 3 to 4 (i.e. assuming research trial yields will be four times higher than yields realised by farmers) decreases the IRR by 22%, from 71% to 55%. Closing the yield gap, from 3 to 2, would have a large positive impact, increasing the IRR by 36%, to 97%. Only monitoring adopters and the yields they are actually achieving over time will provide the evidence needed as to the actual size of this yield gap and whether it is shrinking over time (thus increasing significantly the overall impact of this research).

Table 13. *Sensitivity of results to changes in key parameters.*

Key parameter change	NPV (US$ million)	IRR (%)	B:C ratio
Baseline analysis	606	71	63
Yield discount factor decreased from 3 to 2	1085	97	112
Yield discount factor increased from 3 to 4	364	55	38
R&E costs increased 50%	598	58	42
R&E costs decreased 50%	615	103	127
Ceiling adoption decreased by 50%	299	50	32

Research and extension costs are another difficult factor to measure or predict accurately. We increased our overall R&E costs (estimated by the researchers) by 50% and decreased them by 50% to determine the sensitivity of the results to this assumption. When R&E costs were increased by 50%, the IRR fell by 18%. When they were decreased by 50%, the IRR jumped 45%. Thus it appears that our prediction of positive returns and a respectable B:C ratio is not hugely affected by a large increase in predicted R&E costs; but it is clear that if these costs can be kept down, the net benefits to the research investment look much better.

Predicting adoption lags and ceiling rates of adoption are additional challenges in this type of analysis. Since we felt that an overall adoption period of 20 years is realistic based on a review of relevant ex post assessments, we adjusted our ceiling rates by domain downwards by 50% to examine how much that would affect our reported baseline results. The IRR dropped to 50% (a 30% decrease), and the benefit:cost ratio and NPV were halved. It is apparent that the results are sensitive to assumptions made regarding this parameter, therefore. Our assumed baseline ceiling adoption rates varied across zone according to actual adoption measured in the household survey, with the high population density and good access domain predicted to be the highest, at 43% of cowpea area after 20 years (the other ceiling adoption rates by domain were: LPLM, 0.29; LPHM, 0.35; HPLM, 0.05).

6 Conclusions

This assessment took a novel approach by combining several different research approaches in order to obtain a good understanding of adoption and likely impact of IDPC varieties and associated management strategies. We started with informal group discussions, which contributed some important insights as to how to stratify the sample and which impacts would be quantifiable and which probably would not be, at least in the short-run (even though they should be monitored over time). This was followed by formal surveys at the community and household level. The results of these surveys were useful for gaining an understanding of the characteristics of communities and households that were benefiting from the new technologies, and some insights towards approaches for better targeting of IDPC in the future. Econometric analysis of the survey data confirmed some of the impressions from the group impact workshops – e.g. adoption and benefits are not only occurring amongst the wealthiest households, and dual-purpose cowpea is very important for people in the LPLM domain (i.e. more isolated households). Thus the challenge remains as to how to reach these households with information and new varieties. It is clear that IDPC offers many poor crop-livestock farmers the flexibility to choose management and marketing strategies that suit their particular circumstances – in essence, with only a few new varieties, the farmers are being presented a 'basket of options'. It is also clear that presenting these options to farmers promptly has resulted in critical feedback to researchers, which is already leading to the introduction of more options that will address the needs of a wider variety of households in the future.

In 2000, an estimated 108 million people, 22 million cattle and 65 million sheep and goats were found in the dry savannah zone of West Africa. The results of this study suggest that of the 108 million, 40 million people may fall in the poorest wealth category. Extrapolating from adoption rates cautiously estimated from the household survey suggests a potential cowpea area across the West African dry savannah zone for improved dual-purpose cowpea varieties of 1.4 million hectares, and this ignores other crop area that may be substituted for the new cowpea varieties.

The net present value of the investment in the IDPC research and extension over a period of 20 years is estimated to be in the range of US$ 299–1085 million, the internal rate of return between 50–103%, and the benefit:cost ratio anywhere from 32–127, depending on which baseline assumptions are chosen.

Although we put farming households into four categories – LPLM, LPHM, HPLM and HPHM – in reality they face a wide range of incentives and, in response, exhibit a wide range of management practices. Because responsiveness in adoption of IDPC varieties, and how one ultimately measures impact, depends so heavily on how farmers choose to manage them (e.g. harvesting the grains two or three times until there is no fodder left, or harvesting the grains once and then harvesting a greater amount of fodder), monitoring the whole process of adoption that has begun in this region will be critical. An important lesson emerging from the ongoing research is the extent to which the farmers, researchers and extension workers are learning as they work together to evaluate impact at the different levels and understand the entire learning/diffusion process.

We did not capture many of the benefits, and probably some of the costs, associated with this technology. For example, it is legitimate to ask whether valuing the fodder using a market price is likely to under- or over value fodder that in reality is fed to livestock, and by what amount? The extra costs and challenges involved in quantifying some of these benefits were considered to be too prohibitive at the time this study was initiated, and it was thought that they may best be measured by monitoring some key indicators over the next 5–10 years as uptake of IDPC spreads. The participatory approach during the impact workshop was useful in suggesting what some of these indicators may be. However, IITA/ILRI and partners have recently initiated integrated crop–livestock trials throughout the region (where the crop residues are fed to animals that are monitored, and the manure applied back on the same fields that are also monitored, thus the inputs/outputs of the system as a whole are measured). Since some of the benefits from integrating crops and livestock are only realised in the longer run through the gradual build-up of soil fertility, for example, monitoring over a long period is necessary to measure these environment-related benefits. Social and economic information is also being included in these trials in an attempt to capture the value of livestock as a bank account and insurance substitute (although these benefits will remain tricky to value). When data from several more years of these trials become available (2 years is already available), we should be able to better tackle some of the issues raised in this study that we were unable to address here. It is also clear that participatory approaches aimed at closing the researcher–beneficiary loop will give researchers and policy makers an understanding of these other impacts, and that these approaches have other benefits that should lead to more widespread uptake of new technologies and thus broader overall impact.

Given the changes that are likely to occur in West Africa in the coming three to five decades, in terms of population growth, climate change and land-use change, there is an onus on researchers to streamline the effectiveness of R&E activities to benefit the rapidly increasing numbers of poor people in the region. The lessons learnt from this impact assessment will have much broader applicability to the work of CGIAR Future Harvest centres and their partners in the future than to cowpea research alone. It is hoped that this analysis provides a research and impact assessment strategy that will prove useful for other crops and technologies, and in particular that it provides some guidelines for building assessments of more generic integrated natural resource management strategies and technologies.

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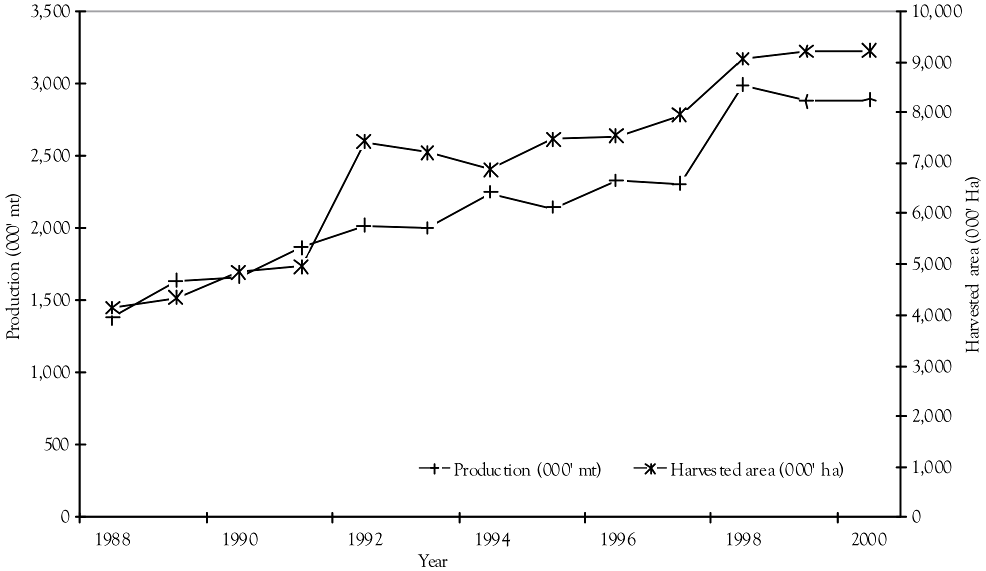
7 Figures



Source: FAO 2001.

Figure 1. *Cowpea production and area harvested: West and Central Africa (1988–2000).*

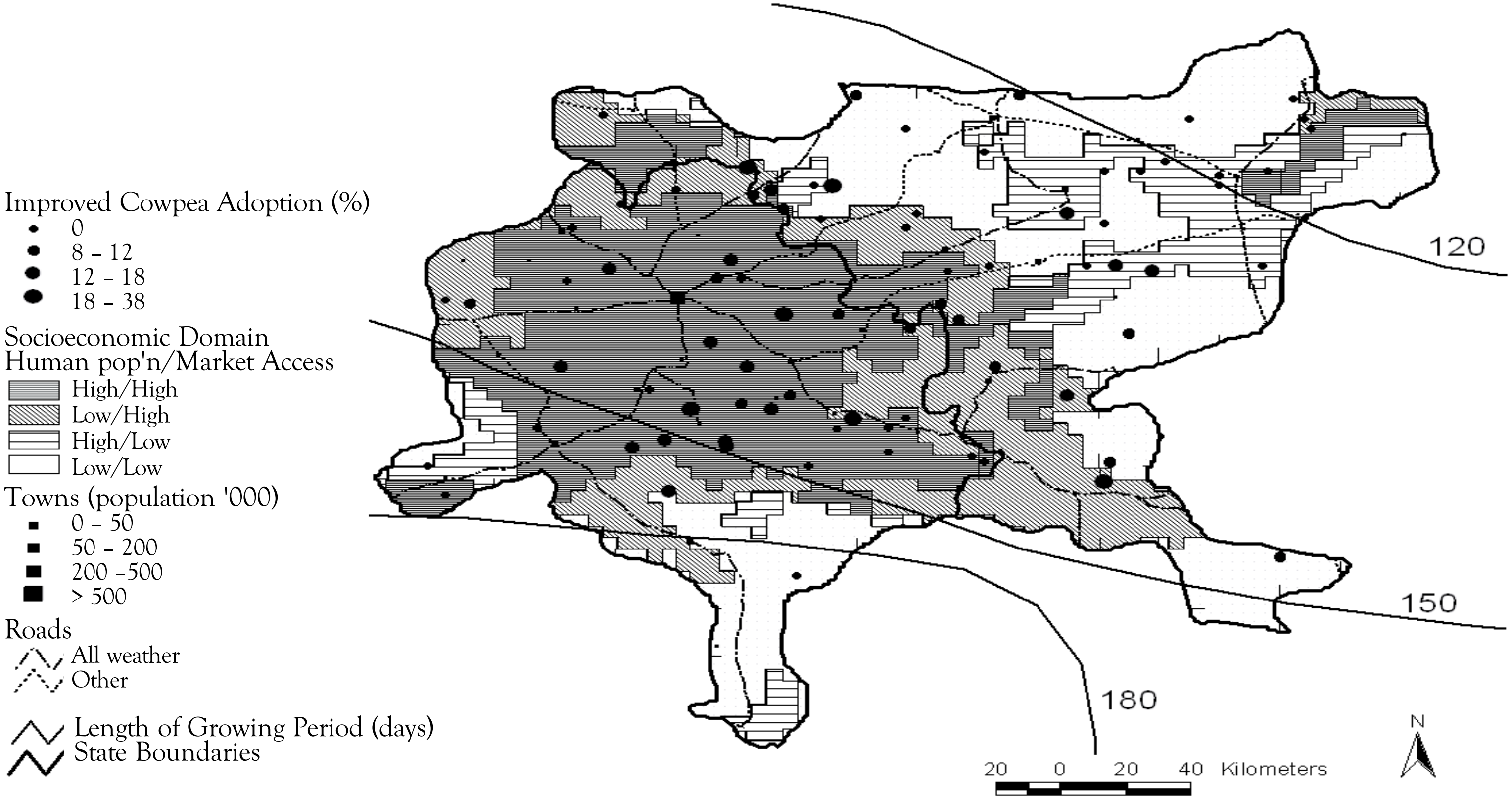


Figure 2. *Socio-economic domains and improved dual-purpose cowpea adoption from village-level survey, Kano and Jigawa States, northern Nigeria.*

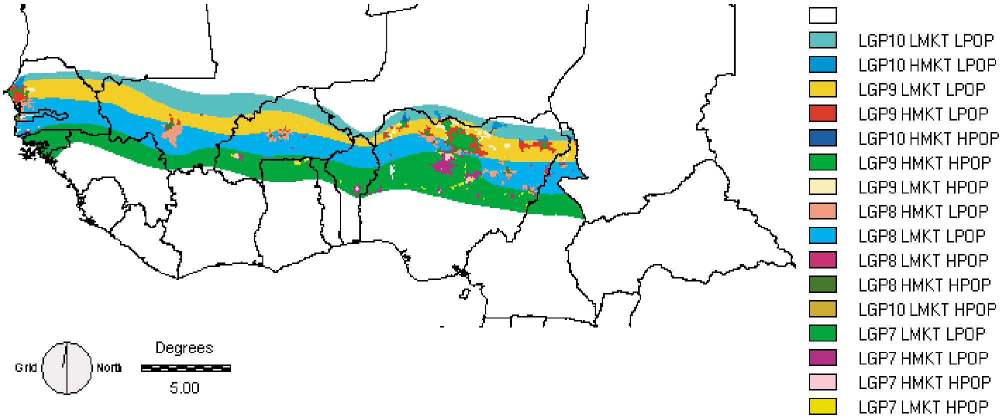


Figure 3. *Dual-purpose cowpea recommendation domains across West Africa based on length of growing period, market access and human population density (see text for details of legend).*

Figure 4. *Cowpea fodder stored in a tree in the Kano region.*

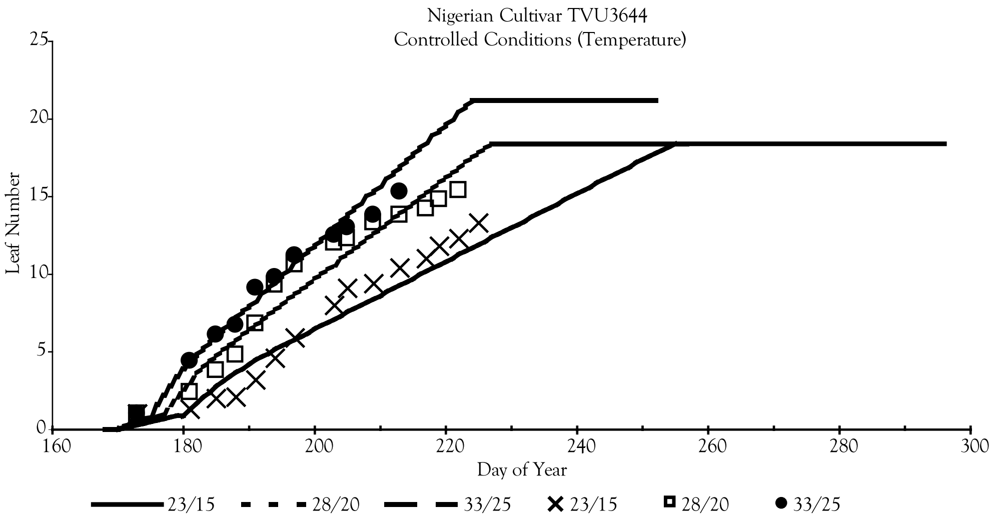


Figure 5. *Comparison of simulated and observed vegetative growth stages for the Nigerian cultivar TVU3644 grown at three different temperature regimes in the Georgia Envirotron.*

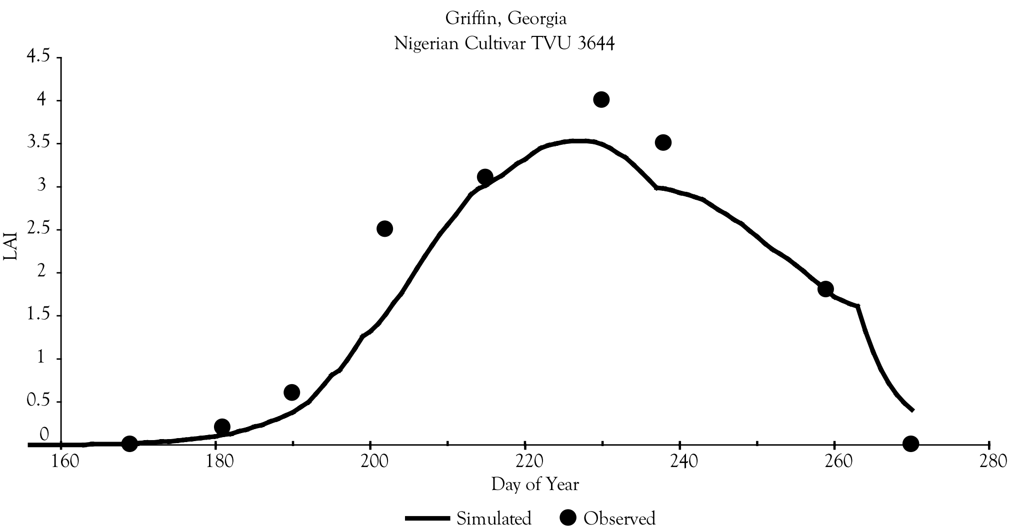


Figure 6. *Observed and simulated leaf area index (LAI) for the Nigerian cultivar TVU 3644 grown under field conditions in Griffin, Georgia, 1998.*

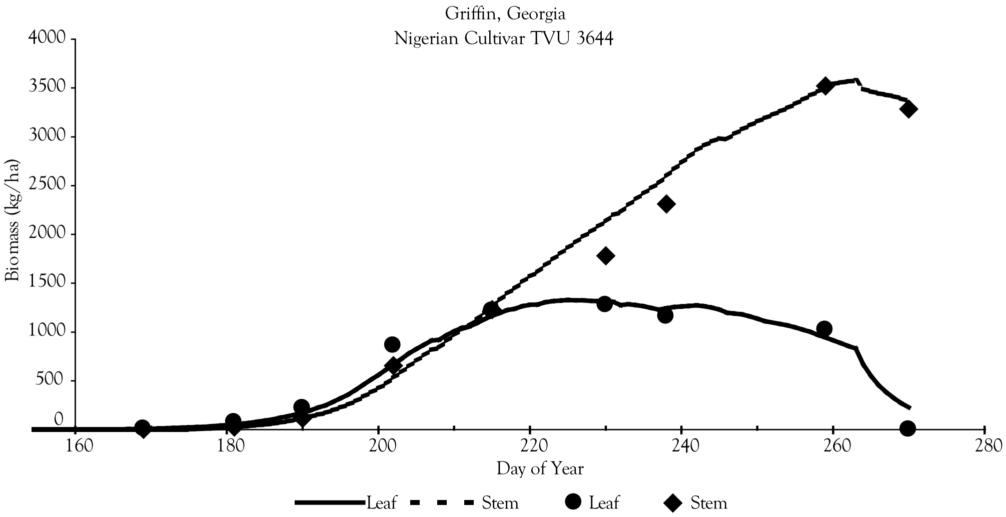


Figure 7. *Observed and simulated leaf and stem weight for the Nigerian cultivar TVU 3644 grown under field conditions in Griffin, Georgia, 1998.*

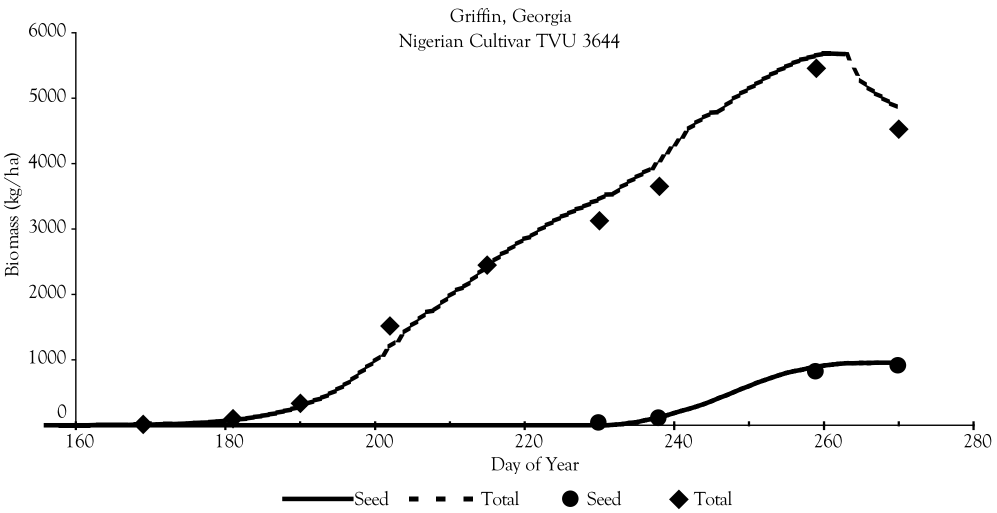


Figure 8. *Observed and simulated above-ground biomass and pod weight for the Nigerian cultivar TVU 3644 grown under field conditions in Griffin, Georgia, 1998.*

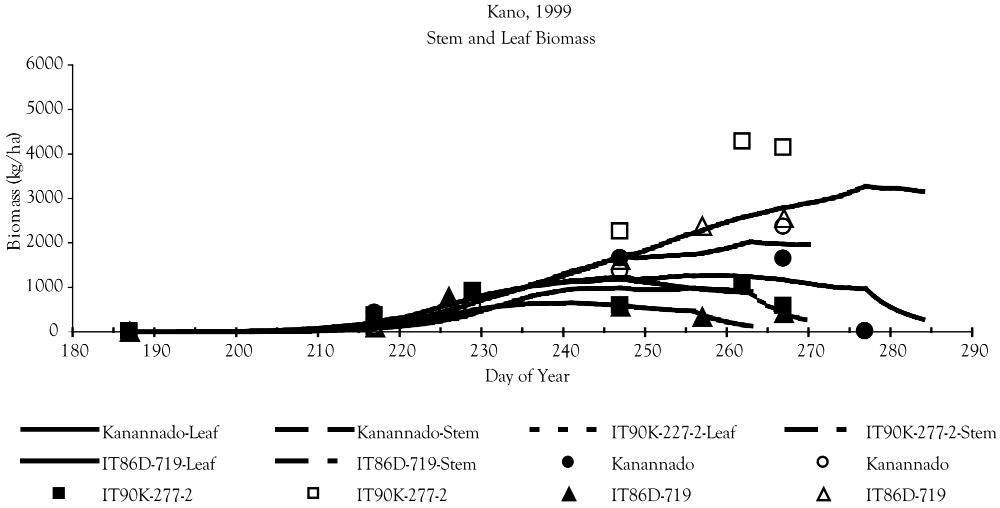


Figure 9. *Observed and simulated stem and leaf weight for IT86D-719 (grain type), IT90K-277-2 (improved dual purpose) and Kanannado (local forage type) grown in Kano during the 1999 season.*

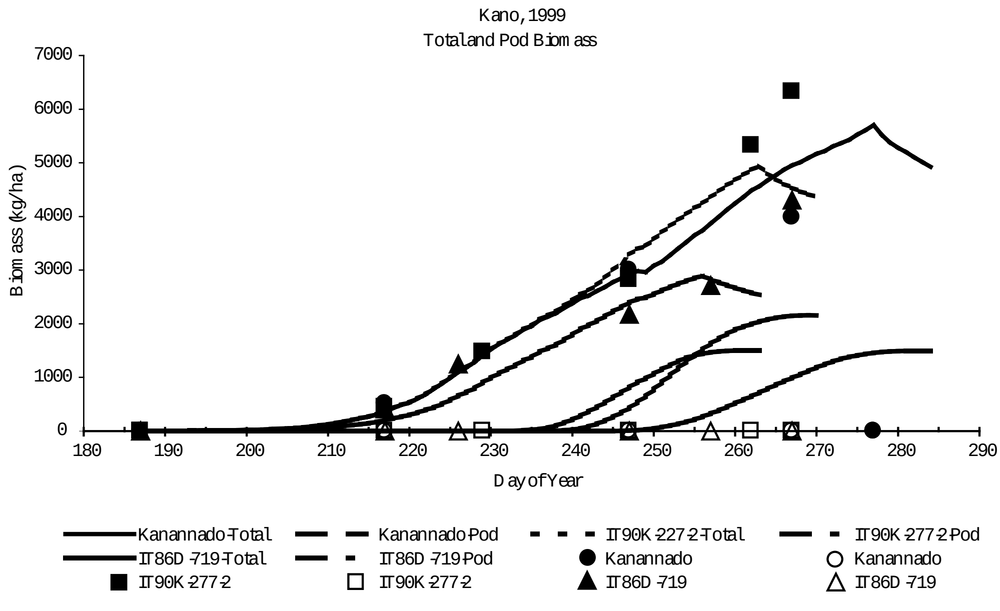


Figure 10. *Observed above-ground biomass and pod weight for IT86D-719 (grain type), IT90K-277-2 (improved dual purpose) and Kanannado (local forage type), grown in Kano during the 1999 season.*

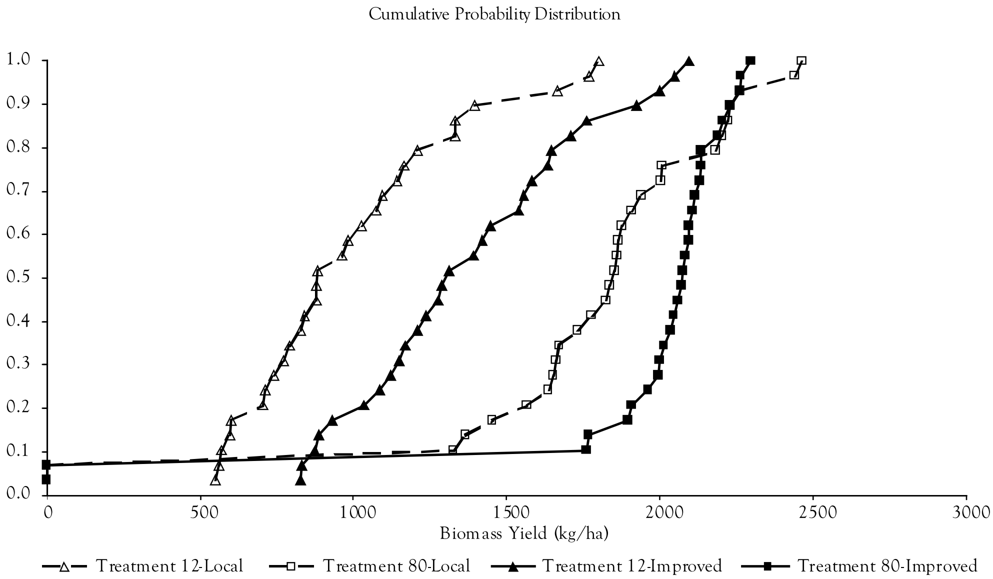
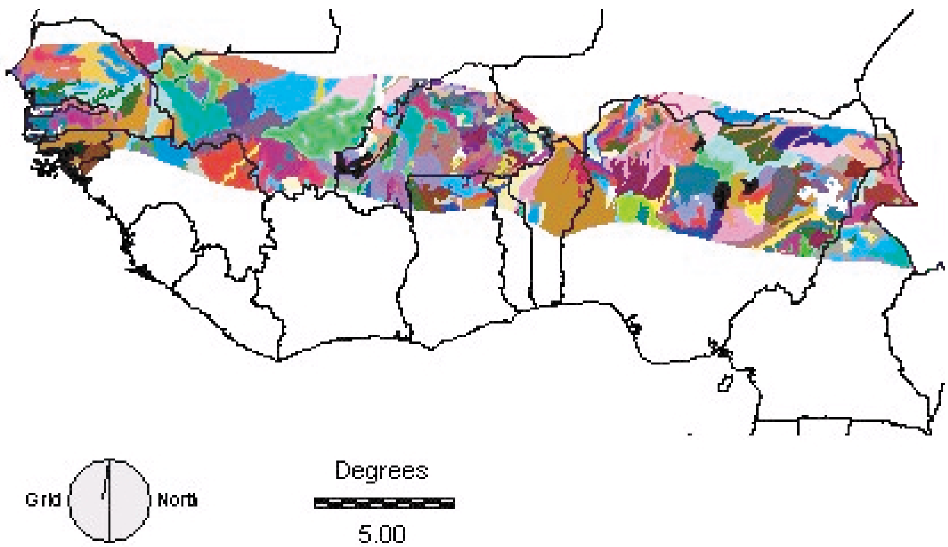


Figure 11. *Simulated cumulative probability functions of biomass yield for local and improved dual-purpose cowpea varieties grown on a Luvic Arenosol (–10.2º longitude, +15.35º latitude, 182 m elevation, treatment 12) and on a Gleyic Luvisol (–5.76º latitude, +13.4º latitude, 274 m elevation, treatment 80).*



Source: FAO 1974, 1995.

Figure 12. *FAO soils map for the cowpea recommendation domains across West Africa*

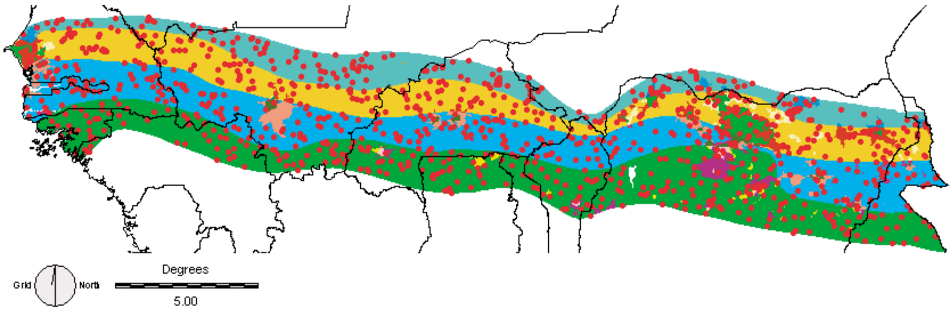


Figure 13. *Sampling sites for CROPGRO-Cowpea across all recommendation domains (legend same as for Figure 3).*

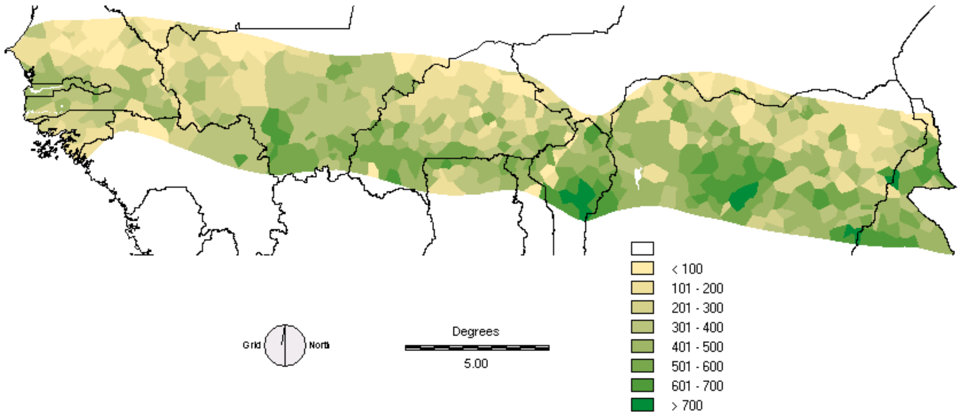


Figure 14. *Simulated mean cowpea biomass yields across all recommendation domains (kg/ha): local variety.*

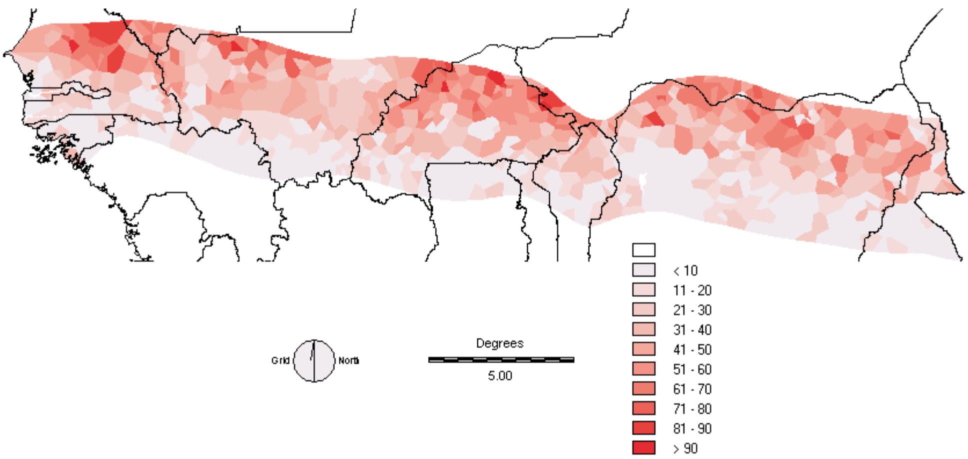


Figure 15. *Simulated cowpea biomass yield coefficient of variation (%) across all recommendation domains: local variety.*

Appendix 1.

Field trials and experiments in West Africa and the U.S. providing input data for the Cowpea CROPGRO model

IITA/ILRI, West Africa

For more extensive model evaluation under different environmental conditions, data were obtained from experiments conducted in West Africa between 1995 and 1997. Locations were Ibadan, Samaru, Minjibir and Mallam Madura in Nigeria and Niamey in Niger. The cultivars used in these trials represented different cowpea accessions of the IITA cowpea breeding programme, the accessions being part of an effort to improve both seed and fodder yield of cowpeas and to develop so-called dual-purpose cultivars. Data collected included those on flowering and harvest maturity dates, as well as final yield.

Trials were established at IITA and ILRI research sites in Ibadan and Kano during the 1999 growing season to allow for extensive model calibration and evaluation of the cowpea growth model. A range of four cowpea accessions was planted at each site, from fodder type (Kanannado) through to grain type (IT86D-719), with IT96D-748 and IT90K-277-2 in between. At Ibadan, the trial was planted in both the first and second wet season. The cowpea accessions were grown as sole crop or intercropped with maize (Ibadan) or sorghum (Kano). First season plots at Ibadan were sprayed twice with insecticide (Sherpa Plus), at flowering and podding, but at Kano and for the second season at Ibadan, a no-spray treatment was also included. The sprayed treatment at Kano consisted of three sprays at 10–14 day intervals, commencing from the onset of flowering. The first two sprays were Sherpa Plus, with the third spray being Karate. Biomass samples were taken 30, 60 and 80 days after planting as well as at 50% flowering and 50% pod maturity. At each sampling time, the dry weight of leaf, stem, pods and grain was estimated and samples of each taken for crude protein and digestibility analyses. Dry matter yields at each sampling time were assessed using the MIXED model of SAS, with the spray and no-spray treatments being analysed separately. Bulked soil samples from three depths, 0–15cm, 15–30 cm and 30–45cm were taken before trial establishment and analysed for pH (in water), N (Kjeldahl), organic carbon, phosphorus (Bray 1) and potassium.

Soil analyses for the trial sites at Ibadan and Kano are summarised in Table A1.1. Total rainfall during 1999 was 1624 mm and 611 mm at Ibadan and Kano, respectively.

Growth-chamber studies, University of Georgia

A pot study was conducted in growth chambers at the University of Georgia's ENVIROTRON facility in 1998 (www.griffin.peachnet.edu/Envirotron.html). The experiment had a factorial design with two levels of carbon dioxide (400 and 750 ppm) and three temperature regimes (23/15, 28/20 and 33/25ºC). The photoperiod was kept constant at 12 hours. Plants were grown in 4-gallon containers filled with sand as a growing medium. The experiment included three cultivars originating from different ecoregions in East and West Africa and Asia. Vegetative and reproductive development were measured every other day.

Flowering in the cultivar from India ranged from 31 days after planting for the 33/25ºC temperature combination to 50 days for the 23/15ºC temperature combination. With the same temperature combinations, the cultivar from Kenya flowered between 38 and 54 days after planting, and the cultivar from Nigeria flowered between 55 and 70 days after planting. The number of days to first seed formation ranged from 42 to 57 days for the cultivar from India, 46 to 70 days for the cultivar from Kenya, and 62 to 77 days for the cultivar from Nigeria. These data show that the period from flowering to first pod and first seed occurrence is less sensitive to lower temperatures than the period prior to flowering. Vegetative growth and development showed a particularly significant response to temperature.

Field study, University of Georgia

A detailed growth analysis study was conducted at the University of Georgia during the summer of 1998. The experiment included three cultivars originating from different ecoregions in Africa and Asia. The crop was planted during the first week of June and supplemental irrigation was applied when needed. Vegetative and reproductive development were recorded at two- to three-day intervals. Growth analysis samples were collected every 10 to 14 days. Yield and yield component data were collected at final harvest.

The cultivar from Kenya showed the most vigorous growth, while growth of the other two cultivars was very similar. The highest yield of 1854 kg/ha was produced by the Kenyan cultivar, while the Indian cultivar had a yield of 1283 kg/ha, and the Nigerian cultivar 900 kg/ha. The highest biomass, including stalk and pod weight, was produced by the cultivar from Nigeria at 4524 kg/ha, compared to 3277 kg/ha for the cultivar from Kenya and 3531 kg/ha for the cultivar from India. This showed that the overall growth characteristics of the Nigerian cultivar were very similar to the fodder-type cowpea crops normally grown in West Africa. Some of the additional growth analysis data are presented with respect to model development and calibration in Section 3.4.

by the total loss of yield in the unsprayed intercrop plot for IT90K-277-2 that could be related to the extremely poor (and uncharacteristic) germination in these plots, but intercrop seed yields were generally lower than sole crop seed yields (Table A1.5). Kanannado did not yield any seed in the presence or absence of insecticide spray, but had the highest fodder yields. Highest seed yield was for IT96D-748 with 1629 kg/ha for the sprayed treatment; this accession also had the highest seed yield of 461 kg/ha in the absence of spray. In contrast to Ibadan, leaf and stem yields for sprayed plots were similar, or higher than those for unsprayed plots, with the highest stem yield of 5561 kg/ha for sprayed Kanannado at 50% maturity and highest leaf yield for this same accession at 80 days after planting but without spray.

Table A1.1. *Soil analyses results from three depths prior to establishment of trial at Ibadan and Kano.*

Location	Soil depth (cm)	pH (water)	N (%)	Organic C (%)	P (mg/kg)	K (cmol/kg)
Ibadan	0–15	6.1	0.097	1.08	4.9	0.14
	15–30	5.8	0.087	1.04	4.4	0.14
	30–45	5.9	0.058	0.28	2.4	0.11
Kano	0–15	6.0	0.038	0.56	25.4	0.22
	15–30	6.0	0.030	0.17	15.0	0.18
	30–45	5.7	0.028	0.14	8.6	0.19

Table A1.2. *Average dry matter yields, first season trial at Ibadan (planted 14 May 1999).*

Accession	Days after planting	Dry matter yield (kg/ha)			
		Leaf	Stem	Pod	Seed
IT86D-719	30	346	199	0	0
	43 (50% flower)	911	910	0	0
	60	681	1191	842	76
	70 (50% mature)	452	787	687	162
	80	154	765	259	115
IT90K-277-2	30	326	219	0	0
	45 (50% flower)	799	923	0	0
	60	795	1392	944	77
	80	575	1645	990	156
	88 (50% mature)	363	1398	674	136
IT96D-748	30	197	124	0	0
	52 (50% flower)	1149	814	0	0
	60	1125	1123	30	0
	80	553	1434	405	57
	82 (50% mature)	940	1373	368	48
Kanannado	30	401	276	0	0
	60	1453	1111	0	0
	80	765	1707	0	0
	110 (50% flower)	919	1461	0	0

All plots were sprayed with Sherpa Plus.
Average yields for sole and intercrop plots are shown here, as there were no significant differences between these.

Table A1.3. *Average dry matter yields, second season trail at Ibadan (planted 13 September 1999)*

Accession	Spray	Days after planting	Dry matter yield (kg/ha)			
			Leaf	Stem	Pod	Seed
IT86D-719	Yes	30	150	51		
	Yes	52 (50% flower)	227	157		
	Yes	60	99	171	82	59
	Yes	80	63	210	191	130
	Yes	93 (50% mature)	47	225	74	50
IT86D-719	No	30	125	44		
	No	52 (50% flower)	202	121		
	No	60	162	191	33	25
	No	80	145	225	16	5
	No	93 (50% mature)	22	174	5	2
IT90K-277-2	Yes	30	164	66		
	Yes	54 (50% flower)	191	140		
	Yes	60	146	198	109	82
	Yes	80	96	318	205	104
	Yes	95 (50% mature)	55	290	67	48
IT90K-277-2	No	30	164	64		
	No	54 (50% flower)	210	149		
	No	60	181	228	16	8
	No	80	261	389	20	7
	No	95 (50% mature)	90	425	19	11
IT96D-748	Yes	30	100	25		
	Yes	52 (50% flower)	149	89		
	Yes	60	65	108	63	44
	Yes	80	33	132	80	53
	Yes	86 (50% mature)	83	114	4	3
IT96D-748	No	30	80	39		
	No	52 (50% flower)	124	73		
	No	60	118	142	18	12
	No	80	69	172	52	31
	No	86 (50% mature)	100	194	29	23
Kanannado	Yes	30	126	46		
	Yes	60	201	189	19	
	Yes	71 (50% flower)	230	262		13
	Yes	80	172	252	147	111
	Yes*	102 (50% mature)	90	363	113	95
Kanannado	No	30	167	66		
	No	60	218	210	0	0
	No	80	259	312	0	1
	No	85 (50% flower)	267	343	0	
	No*	102 (50% mature)	236	502	13	7

* For Kanannado, 50% maturity was recorded as 102 days for sole plots, but 121 days for intercrop.
Average yields for sole and intercrop plots are shown, as there were no significant differences between these.

Results, first season trial at Ibadan (Table A1.2)

There were no significant differences in dry matter yields at any sampling time between the sole and intercropped plots. Therefore, results were subsequently assessed on the basis of means for the sole/intercropped plots. There were significant differences ($P<0.05$) between accessions for dry matter yields of all components at the five sampling times except for leaf yield at 50% flowering and leaf and pod yield at 50% maturity. Kanannado had the highest fodder yield (leaf plus stem) at 30, 60 and 80 days after planting, with a higher proportion of leaf than the other accessions. However, it flowered very late (110 days after planting), and the plants were then destroyed by fungus attack to the extent that it was not possible to harvest at maturity. Variety IT86D-719 flowered earliest (43 days after planting) and together with IT90k-277-2 had the highest seed and pod yields. The latter also had good fodder yields and behaved as a dual-purpose variety under these conditions.

Second season trial at Ibadan (Table A1.3)

Again, there were no significant differences in dry matter yields at any sampling time between the sole and intercropped plots, and results are presented as means of these two treatments in Table A1.3. The days after planting to 50% maturity for Kanannado differed according to cropping pattern, with the sole plots reaching 50% flowering 102 days after planting, whereas for the intercropped plots this was 121 days after planting. However, the dry matter yields of the various components did not differ significantly. At all sampling times there were significant differences ($P<0.05$) between the dry matter yields for all components except for leaf at 30 days after planting, pod and seed 80 days after planting, leaf and seed at 50% maturity for the sprayed plots and pod and seed yields at 60 days after planting and 50% maturity. For all four accessions, seed yields were very low from unsprayed plots, with the highest seed yield in the absence of spray recorded as 31 kg/ha for IT96D-748 at 80 days after planting. Kanannado yielded almost no grain at all in the absence of spray, but had the highest stem and leaf component yields of 502 kg/ha at 50% maturity and leaf yield 267 kg/ha at 50% flowering. In the presence of spray, highest stem yield was for Kanannado at 50% maturity and leaf yield 261 kg/ha for IT90K-277-2.

Trial at Kano (Table A1.4)

Leaf dry matter yields were significantly different with or without spray except for the yield at 50% flowering with spray and that for 50% maturity without spray. Stem yields differed less, with only yields at 60 days after planting and 50% maturity differing significantly for sprayed treatments and those for 60 and 80 days after planting for the no-spray treatment. Seed yields were assessed only at maturity and differed significantly. Unlike the Ibadan trials (and many other trials in Kano), there were significant differences in seed yield between the sole and intercrop plots. This was partly influenced

Table A1.4. *Average dry matter yields, trial at Kano.*

Accession	Spray	Days after planting	Dry matter yield (kg/ha)			
			Leaf	Stem	Pod	Seed
IT86D-719	Yes	30	322	93		
	Yes	39 (50% flower)	785	466		
	Yes	60	566	1612		
	Yes	70 (50% mature)	336	2376		1336
	Yes	80	416	2554		
IT86D-719	No	30	372	94		
	No	40 (50% flower)	692	471		
	No	60	574	1225		
	No	72 (50% mature)	559	2025		337
	No	80	417	1753		
IT90K-277-2	Yes	30	354	92		
	Yes	42 (50% flower)	908	565		
	Yes	60	575	2247		
	Yes	75 (50% mature)	1055	4268		1629
	Yes	80	569	4129		
IT90K-277-2	No	30	337	97		
	No	43 (50% flower)	894	428		
	No	60	686	3024		
	No	75 (50% mature)	930	2626		315
	No	80	700	2760		
IT96D-748	Yes	30	233	50		
	Yes	55 (50% flower)	795	740		
	Yes	60	818	1583		
	Yes	80	565	3622		
	Yes	80 (50% mature)	750	2605		1525
IT96D-748	No	30	224	56		
	No	55 (50% flower)	452	466		
	No	60	591	960		
	No	80	763	2126		
	No	80 (50% mature)	793	2002		461
Kanannado	Yes	30	414	99		
	Yes	60	1649	1352		
	Yes	80	1631	2350		
	Yes	90 (50% flower)				
	Yes	115 (50% mature)	687	5561		0
Kanannado	No	30	385	102		
	No	60	1172	1051		
	No	80	1657	2214		
	No	90 (50% flower)				
	No	115 (50% mature)	626	3948		0

For the spray plot, only values for sole crop plots are given. No-spray plots are the mean of sole and intercrop plots.

Table A1.5. *Average seed yields for sole and intercrop plots for the trial at Kano.*

Accession	Spray treatment	Seed yield (kg/ha)	
		Sole crop	Intercrop
IT86D-719	Spray	1336	
	No spray	438	236
IT90K-277-2	Spray	1629	
	No spray	631	0
IT96D-748	Spray	1525	
	No spray	773	149
Kanannado	Spray	0	
	No spray	0	0

Appendix 2.

Economic surplus model assumptions

The critical assumptions used in the spreadsheet analysis of total economic surplus (benefits) to adoption of improved dual-purpose cowpea were as follows. The economic surplus spreadsheet model is available upon request from the authors.

1. Area to all types of cowpea for the dry savannahs was estimated by multiplying percentage area down to cowpea from the household survey for each domain (LPLM, 0.3; LPHM, 0.33; HPLM, 0.29; HPHM, 0.3) by the total cropped area (LPLM 12,968,088 ha; LPHM 1,319,040 ha; HPLM 1,074,106 ha; HPHM 859, 375 ha), using the GIS estimates as outlined in Section 3.2.
2. Total cowpea grain production for the dry savanna zone (i.e. starting quantity, using traditional technology) was equated with the estimated area under cowpea multiplied by average yield per hectare for cowpea grain under traditional technology. Average yields by domain were obtained from the crop modelling work (see Table 7), to which a yield discount factor of 3 was applied. In other words, the simulated grain and fodder yields were divided by 3 to account for the differences between the more ideal conditions represented by research station trials and the less ideal conditions found on farm.
3. The estimated area under cowpea (and therefore quantity of cowpea produced) was assumed to grow annually at the observed rate of growth for total cowpea area by domain from 1999 to 2000 in the household survey, divided by 20. (This represents 20 years, since the observed growth rates were considered very high for a one-year period, and we are extrapolating to a much wider area where conditions may differ significantly from those found in our study area; see Table A2.1.)
4. The ceiling adoption rate in 2020 was assumed to be the observed ratio of improved dual-purpose cowpea to the total cowpea area for the surveyed households for each domain (LPLM, 0.29; LPHM, 0.35; HPLM, 0.05; HPHM, 0.43), working backwards to a zero adoption rate in 2000, assuming an s-shaped adoption curve over 20 years. These ratios were assumed to be ceiling rates because the sample was purposely selected to include villages where adoption has occurred, and we wanted to extrapolate to wider areas where no adoption has yet occurred.
5. Additional costs associated with adoption of new varieties were assumed to be USUS$ 17.00 per ha based on a 2000 cost of insecticide in Bichi of N850 per litre (Upper Cott), sprayed at the rate of 1 litre per ha, and assuming two sprayings per crop (i.e. a total cost of N1700/ha, or around US$17/ha.
6. The total research and extension costs were estimated to be US$5 million in 2000, which was intended to include all costs prior to 2000, US$3 million in 2001 and

2002, US$2 million in 2003 and 2004, and US$1 million in 2005, 2006, 2007, 2008 and 2009. Since these costs are difficult to predict precisely, they are estimates of the magnitudes of expenditures that may be required by the various agencies and players involved in R&E throughout the dry savanna region if the levels of adoption currently seen in northern Nigeria are to be attained across the broader target zone for this technology.

Table A2.1. *Cowpea area by domain and growth from 1999 to 2000.*

Domain	Total cowpea area 1999 (ha)	Total cowpea area 2000 (ha)	Percent increase, 1999 to 2000
LPHM	170	185	9
HPHM	265	314	19
LPLM	230	264	15
HPLM	402	427	6
Total	1066	1189	11.5

n = 462 households

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