Integrating science with farmer knowledge:
Sorghum diversity management in north-east Ghana

Supervisors: Prof. dr. P. Richards
Hoogleraar Technologie en Agrarische Ontwikkeling
Wageningen Universiteit

Prof. dr. ir. P.C. Struik
Hoogleraar Gewasfysiologie
Wageningen Universiteit

Prof. S.K. Offei
University of Ghana, Legon

Dr. P.B. Atengdem
University of Ghana, Legon

Promotiecommissie:

Prof. dr. K.E. Giller	(Wageningen Universiteit)
Prof. dr. J. Jiggins	(Wageningen Universiteit)
Prof. dr. J.P. Tetteh	(University of Cape Coast)
Prof. dr. D. Millar	(CECIK – The Centre for Cosmovision and Indigenous Knowledge, Ghana)

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Comfort Y. Kudadjie

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Abstract

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Sub-optimal impact of agricultural research is connected to lack of involvement of farmers. This is especially true for Africa where problems are diverse and complex. Farmer participation might help research to become better focused and resulting technologies more adopted. However, linking researchers and farmers effectively in research is not easy. Even though African farmers are often very innovative, technology development is influenced by other stakeholders and takes place within a wide institutional context and policy framework over which farmers have little control. Convergence of Sciences offers an alternative way of organizing research whereby the agricultural innovation process is recognized as a multi-stakeholder process.

This thesis situates science and farmer initiative within the context of sorghum genetic resource management. Sorghum plays a pivotal role in the agrarian life and culture of small farmers in north-east Ghana. The value of genetic diversity for farmers provides strong justification for placing emphasis on, and pursuing research into, two main areas: the need to support farmers' own efforts in diversity management and variety maintenance, and – as an important component of that aspect – the need to pay attention to farmers' seed management and storage practices.

The thesis shows how farmers and scientists can effectively engage in agricultural research towards a sustainable use and management of sorghum genetic resources. Convergence is explored between researchers and farmers and between the biosciences and social sciences. The possibility for convergence between farmers, public sector researchers and private sector interests under market-driven conditions for sorghum production is also explored.

The results indicate that joint learning and experimentation under local conditions is a useful and effective means through which unschooled small-scale farmers and scientists can actively engage in the research process. Such an approach provides the opportunity for an intensive and sustained interaction between both farmers and scientists. Going along the pathway of experimentation has shown that farmers are capable of joining in scientific research, have an indigenous capacity for astute observation, and are capable of forming a good working notion of science as it is practised in the formal sector. However, a conscious effort must be made to embed these scientific principles in the farmers' local and cultural context in order to make the capability of farmers as co-researchers become more apparent. Through farmers' own analysis (facilitated and stimulated by researchers) of test data, they correctly infer that in order to improve the physiological seed quality of their early maturing varieties, they need to pay closer attention to the conditions under which harvesting, seed selection, and storage occur.

Scientific methods and tools from the biological and social science disciplines are used for gathering and analysing qualitative and quantitative data during the joint learning and experimentation phase of the study and for generating knowledge. Molecular marker techniques from bioscience helped to determine the extent of diversity used by farmers, while anthropological information provided a deeper understanding of how cultural and socio-economic factors influence farmers' use and management of sorghum varieties.

The case of contract farming provided the important lesson that making contract farming work is often contingent upon mobilizing both technical and farmer knowledge for technological problem solving. Making technology part of the contracting process helps reinforce among all contracting parties the need to work jointly towards effective solutions to production problems in an uncertain world where effective new knowledge is at a premium. This requires the recognition by contracting companies of the fact that where the technology is an important problem, offering ways of negotiating about the various contributions of relevant parties in the contract would lead to better application of technology.

Sorghum remains an important crop for farmers who stand to gain a lot more if researchers commit and apply themselves to partnership with farmers as co-researchers. This thesis has thrown some light on how such partnerships for new and effective knowledge might evolve. Convergence of Sciences, as an alternative approach to the linear model of planning, designing and implementing research, appears to hold much promise for small farmers such as those found in the north-eastern part of Ghana.

Keywords: Convergence of sciences, diversity management, experimentation, farmer knowledge, genetic diversity, Ghana, plant variation, private sector, research, *Sorghum bicolor* (L.) Moench, small-scale farmers, seed quality.

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Contents

CHAPTER 1

General introduction

Concerns over lack of benefits from agricultural research for small farmers

Over the past two to three decades pressure has been mounting on agricultural research to produce results with more reaching benefits for small farmers than is currently the case. A key area of concern about the ineffectiveness of research is crop improvement. In Asia, the Green Revolution has had an almost pervasive impact (Evenson & Gollin, 2003); but elsewhere farmers have enjoyed little from formal crop breeding (Almekinders & Elings, 2001; Chambers & Jiggins, 1987a, b; Lipton & Longhurst, 1989). Sub-Saharan Africa (SSA) in particular has been described as achieving a very partial Green Revolution. Yield increase per unit area through introduction of high-yielding varieties has been especially limited (Evenson & Gollin, 2003). Disappointing impact is attributed to poor performance of modern varieties and farmers' low use of them (Dorward *et al*., 2004). For sorghum in SSA, for example, average yields have decreased since 1980 (Ahmed *et al*., 2000). Two reasons why the region has benefited so little from formal improvement are thought to be agro-ecological complexities and the failure to produce varieties that address farmers' needs (Almekinders *et al*., 1994; Cromwell *et al.,* 1993; Evenson & Gollin, 2003; Sperling & Loevinsohn, 1993).

The limited contribution of agricultural research (including crop improvement) has also been blamed on lack of involvement by small farmers (Farnworth *et al*., 2003). Farmers are excluded because of a linear approach in which research is seen as a source of technology, extension as the delivery mechanism, followed by a straight-forward adoption by farmers (Bruin & Meerman, 2001; Röling, 1996). But increasingly, it has been argued that sub-optimal research impact is connected to lack of involvement of farmers, especially in Africa where problems are diverse and farmer participation might help research to become better focused (Gibbon, 2002; Okali *et al.*, 1994; Röling *et al*., 2004).

Participation in research as an element in improving research impact

It is now accepted that if agricultural research organizations are to be effective then agenda and output need to be more demand-led than in the past (Scarborough, 1996).

In the quest for ways to ensure that research programmes are determined by farmer priorities different participatory approaches have been developed. These have gradually moved from an initial consultative mode of participation to a collaborative and collegial mode of farmer participation, and finally to farmer empowerment in the innovation process (Biggs, 1989; Farrington & Bebbington, 1993; Heemskerk, 2004; Pretty *et al*., 1995).

Participatory approaches in research

In the 1970s, farming systems research (FSR) was introduced partly in response to the early Green Revolution experience and during this period the emphasis was on getting a better understanding of local farming systems for successful technology development. FSR was characterized by the testing and adapting of technology in on-farm trials. However, the major critique of this type of research was that (1) broader policy issues were not addressed (Biggs & Farrington, 1991), (2) though research agendas were identified through farm-based diagnostic exercises, analysis continued to be made by the formal research system (Okali *et al*., 1994), and (3) the process remained largely insensitive to farmers' knowledge as farmers were often considered as research subjects or passive components of the system under investigation (Chambers, 1992; Cornwall *et al*., 1994).

Farmer participatory research (FPR) approaches emerged in the wake of these criticisms in a more deliberate attempt to actively involve farmers in setting the research agenda, in planning, and in prioritizing technological needs (Killough, 2005). At the same time on-going research revealed that farmers also carry out their own research, do experiments, and possess valuable knowledge (Biggs, 1989; Rhoades & Bebbington, 1991; Richards, 1985, 1986). This led to attempts to incorporate farmers into programmes of technology development and involve them in implementing trials and on-farm testing. Thus, this recognition of local knowledge held by farmers led to a focus on the farmer as an innovator and experimenter, and a greater interest in collaborative relations between researchers and farmers (Amanor, 1990; Farrington & Martin, 1988). In the late 1980s, the concept of FPR or participatory technology development (PTD) emerged, based on this recognition. But although this approach to research was seen as a definite step in moving farmers from a consultative role to a collaborative one (Biggs, 1989), it was felt that a collegiate role in which researcher worked with farmers to strengthen their own innovative capacities was a more desired objective (Berg, 1993; De Boef *et al.*, 1993; Eyzaguirre & Iwanaga, 1996; McGuire *et al*., 1999).

However, achieving this form of collegiate research, effectively linking farmers and researchers, has not been easy. This is because technology development itself takes place in a wider context of institutional and policy frameworks over which small farmers (especially in Africa) have little control. Farmers have no institutional influence over decisions about agricultural research, and extension services and national agricultural institutes in developing countries find themselves trying to adapt the products of research from international research centres which do not fit the local conditions of farmers or reflect their perspectives (Amanor *et al.*, 1993). There is a lack of markets and a slow development of other institutional support structures such as credit provision and input supply needed to support technology development (Röling *et al.*, 2004). This suggests that apart from farmers there are other societal stakeholders whose roles directly or indirectly influence the usefulness of the contributions that agricultural research seeks to make to the lives of small farmers. So, although African farmers are very innovative, and have applied their local knowledge to support their agricultural production systems over the centuries – see Jusu (1999) on hybridization of *Oryza sativa* and *Oryza glaberrima* by farmers in Sierra Leone, an innovation more recently claimed by science, and farmers' adaptive strategies to cope with emergence of weeds in Benin (Vissoh *et al.*, 2004) – the windows of opportunity they are able to support remain very small.

The challenge, then, is for researchers to understand the wider context in which farmers find themselves, to identify and target the small windows through which agricultural research can make a contribution, and to make informed strategic choices about what type of research to invest in. A different form of organizing research is required which not only takes cognizance of the fact that the agricultural innovation process is a multi-stakeholder process involving research institutions and other important societal stakeholders (including farmers), but which also seeks a way to develop these wider interactive relations. There is no agreed way to go about this task. Situating science and farmer initiative within this broader context is a central challenge addressed in this present thesis.

Convergence of Sciences as an alternative approach to conducting agricultural research

Based on the understanding that agricultural innovations (i.e., technology, procedures, new forms of organization and new ways of interacting) are generated through a strong multi-stakeholder participation in agricultural development (Anon., 2001), 'Convergences of Sciences' (CoS) suggests an alternative approach to agricultural research. CoS recognizes and places emphasis on the role of (multi-) stakeholders in conducting research useful for and involving those for whom it is conducted. It therefore advocates an interactive science, where knowledge is collectively generated through the interaction of different actors with potentially complementary roles. So CoS recognizes that scientific institutions do not have the monopoly of science, but rather the emphasis is on the democratization of sciences (Anon., 2001). Therefore all stakeholders contribute and converge in terms of their perception of context, theories and values, and agree on collective action with respect to their common problems. The aim is an interactive problem identification, and development of solutions with emphasis on the knowledge and problem solving capabilities of the stakeholders involved.

The underlying principle of the CoS approach to agricultural research on improved livelihoods of farmers is an emphasis on inter-disciplinarity and trans-disciplinarity. Inter-disciplinarity is an essential element in which the social and natural sciences work together to contribute to problem solving within a given context, and to create new knowledge or modes of thinking (Jiggins & Gibbon, 1997; Gibbon, 2002; Tress *et al*., 2003). In trans-disciplinarity there is an integration of different stakeholders including academic researchers, farmers and other user-group participants, all seeking a common research goal.

Thus, convergence of sciences suggests that agricultural science and research pursue a new professionalism – a 'post-normal science' – in which scientists go beyond standard approaches, seeking to learn from and with farmers and other relevant stakeholders, to develop new roles, new concepts, and values and methods (Funtowicz & Ravetz, 1993). As Chambers (1993) puts it, this professionalism is "not a rejection of modern scientific knowledge but a broadening and balancing" to give a new primacy to the realities and analysis of poor people themselves. From the viewpoint of convergence of sciences therefore, stakeholder participation is not opposed to science and neither does one replace the other. In effect, farmers, researchers, and resource managers all participate in the innovation process and engage in learning and knowledge sharing.

Learning here refers not only to transferring knowledge but to the outcome of a co-operative inquiry between people with similar concerns who work together as co-researchers to develop new ways of looking at things. Every one partakes in the design and management of the inquiry; everyone gets into the experience and action being explored and everyone is involved in making sense and drawing conclusions; thus, everyone exerts influence on the process (Heron & Reason, 2001).

In this type of cooperative and interactive research, different types of knowledge – scientific knowledge and local knowledge – also interact and are exchanged. The result of this interaction is a co-construction of useful knowledge (Hounkonnou *et al*., 2006; Van Dusseldorp & Box, 1993) and the development of shared understanding among stakeholders. But this implies that methodologies for effective interaction and exchange of information between farmers and scientists are needed. Convergence is therefore a matter of methodology and deals with how to achieve effective inter-disciplinary and trans-disciplinary cooperation between science and craft sectors (Richards, 2003). So the important question that we need to answer is: how can the element of participation and science be merged to form the hybrid system that CoS envisages? In effect, how does democratized science become operational in agricultural research?

Converging sciences in plant genetic resource management?

Farming communities play a crucial role in the management of plant genetic resources (Bellon & Brush, 1994; De Boef & Almekinders, 2000; Eyzaguirre & Iwanaga, 1996; FAO, 2004; Hardon & De Boef, 1993). They develop agricultural crops and varieties through a process of continuous cultivation, adaptation and experimentation. They decide what crops and varieties to select; they store and exchange seeds with other farmers, and replace their varieties from time to time.

There is substantial evidence that farmers maintain and select among their landraces (Jusu, 1999; Richards, 1995; Riley, 1996; Soleri *et al*., 1999; Weltzien *et al*., 1996). Many of the varieties maintained and used by farmers – largely local – meet several different needs of small farmers and represent a valuable resource for farmers and mankind in general (Jarvis *et al*., 2004; Rijal *et al*., 2000; Smale *et al*., 1999b). Formal breeding relies heavily on landraces that are found in centres of crop diversity for crop improvement. While gene banks can help to maintain crop genetic diversity *in situ* this strategy is not considered adequate to ensure that diversity is conserved and used (Van Hintum, 1994; Wood & Lenné, 1997). Maintaining crop diversity in farmers' fields is becoming an important and complementary strategy to gene banking and increases the diversity available to farmers and breeders (Almekinders, 2001; Almekinders & De Boef, 2000).

The fact that farmers experiment with and possess knowledge about their crops is now widely acknowledged and proven in different parts of the world (Bellon, 2001; Longley & Richards, 1993; Millar, 1993; Prain *et al*., 1999; Richards, 1995, 1997; Sperling & Loevinsohn, 1993). Farmers' knowledge and skills in managing diversity is essential for local crop development as well as formal breeding. Almekinders (2001) suggests that recognizing farmers' capacity in variety maintenance and seed selection is a first step in building an effective plant genetic resource system for the use, development and conservation of crop genetic diversity. However, farmers vary in their capacity to manage diversity, so beyond recognizing farmer's knowledge and capacity it is also necessary to find effective ways of strengthening their efforts or enhancing their skills in genetic resource management.

Over the past decade or so, participatory approaches to crop improvement have developed ways of bringing researchers into closer collaboration with farmers for crop improvement purposes (Eyzaguirre & Iwanaga, 1996; Sperling & Loevinsohn, 1996). Several of these approaches – for example, participatory plant breeding (PBB) and participatory variety selection (PVS) – have placed more emphasis on the technical aspects of breeding (see McGuire *et al*. (1999) and Weltzien *et al.* (2000) for reviews of such cases) and typically involve scientists asking farmers about their desired traits in a crop variety, farmers selecting among genetically segregating lines or farmers evaluating material developed by breeders.

Apart from the concern that most of these approaches have merely been a consultative add-on to a 'conventional' breeding programme, little specific attention has been paid to farmers' practices and activities in genetic resource management and seed production and management (McGuire, 2005). However, the management of plant genetic resources by farmers is an integration of seed production, crop development and in *situ* maintenance (Almekinders, 2001). The integrated nature of genetic resources systems implies that support to local plant genetic resource management also include support to farmers' seed production. Although there is ample evidence of local production of quality seed, in several cases farmers' seed production and storage are sub-optimal, affecting seed vigour and health and ultimately, seed quality.

Among authorities supporting farmers' genetic resource management practices, such as enhancing farmers' skills in seed selection, a knowledge and technology transfer approach is often preferred, e.g., teaching farmers basic genetics through training workshops (Gómez & Smith, 1996; Saad *et al.,* 2001). However, farmers' knowledge and practices in genetic resource management occur in specific contexts and have both social and cultural dimensions which need to be understood (Saad, 2002; Scoones & Thompson, 1994).

The recognition that farmers are key stakeholders in managing plant genetic resources, and that the capacity to manage is supported by systems of knowledge and practices shaped by specific social and cultural contexts, implies it is important first to understand local knowledge and the context within which resources are managed, in order to determine how to link scientists and farmers together effectively in order to make a useful contribution to farmers' knowledge and practices in managing plant genetic resources.

This thesis explores the prospects for a convergence of sciences approach to managing sorghum genetic diversity in north-east Ghana. Convergence is explored in two broad contexts: between researchers and farmers as two important stakeholders in sorghum genetic resource management; and the possibilities for convergence between farmers, public sector researchers, and private sector interests under market-driven conditions for sorghum production. Convergence between biological science and social science is also covered.

In the next section, an overview is provided covering why this thesis focuses on sorghum by showing the importance of the crop in Ghana, the role of and efforts in research focused on development of sorghum, the interest of the private sector in the crop, and general problems faced in producing the crop at the national level, and thus why renewed attention needs to be paid to sorghum.

Sorghum in Ghana

Production

Sorghum (*Sorghum bicolor* (L.) Moench) is an important cereal crop in Ghana whose cultivation is primarily in the hands of small-scale farmers with average land holdings of not greater than 2 ha. It is mainly grown in the Guinea and Sudan savannah Zones, which are found in the Upper West, Upper East and Northern regions of the country. Together with millet, it forms the basis of the farming systems in these regions. Of the cereal crops grown in Ghana, sorghum ranks second in terms of the area cultivated. About 303,000 Mt of sorghum are produced on 346,000 ha (Statistics, Research and Information Directorate [henceforth SRID], 2004). Farmers use few external inputs such as organic fertilizers. Average yields are about 0.9 Mt ha^{-1} although yields of about 2 Mt ha^{-1} are achievable (Atokple, 1995; SRID, 2004).

Importance of sorghum

Sorghum is a staple and a multi-purpose crop. The milled grains are used in preparing food (*tuo zaafi, koko* and *masa*) and the local opaque beer known as *pito*. Sorghum brewing is an important cottage industry in northern Ghana. The leaves of sorghum serve as fodder for farm animals while the stalks are used for fencing, staking, roofing, weaving baskets and mats and also for fuel. Beyond food security and provision of cash the value of sorghum is linked to the social, economic, religious, nutritional, and health aspects of farmers' lives.

Sorghum is mainly cultivated and consumed by the lower strata of society. The three Northern regions where it is widely grown are among the poorest. More than 40% of the population in these regions lives below the poverty line (Ghana Statistical Service, 2000). The regions of cultivation are characterized by poor soils, high population pressure, erratic rainfall, and high temperatures (Webber, 1996). The resilience of sorghum – in terms of drought resistance and ability to withstand high temperatures – makes it crucial for food security in these regions.

Status of sorghum

As the second most consumed cereal crop in Ghana (SRID, 2004) sorghum has attracted surprisingly little attention from research. The number of research projects and scientist time (person-years) spent on sorghum are low. In 1993, while maize recorded an average of 96.7 research projects and 12.2 scientist-years; and rice 36 projects and 8.7 scientist-years; the average number of sorghum projects was only 6.5 with 2.2 scientist-years (Anon., 1994b). This low number of scientist-years devoted to sorghum is reflected in the low number of varieties turned out after almost six decades of research effort (only seven varieties, see below), compared to 12 varieties of maize in two decades and 15 varieties of rice recommended or released in three decades (Alhassan & Jatoe, 2002).

Documentation in the form of reports and publications related to agricultural problems from 1970–1994 in Ghana showed that cereals had more publications than any other commodity group. However, only 5% were on sorghum and millet while 64.5% were on maize and the remaining 30.5% on rice. Although large numbers of publications on a topic/commodity is not necessarily an indicator of good research, their absence is a strong indicator that not much work of any kind has been done.

Research efforts and interest in sorghum

The Savanna Agricultural Research Institute (SARI – formerly Nyankpala Agricultural Experimental Station [NAES]) has the mandate for conducting research on sorghum in Ghana. Research on sorghum started in the 1940s and concentrated on screening local germplasm and introductions from West Africa, South Africa and the USA. Sorghum improvement efforts in the country faced serious drawbacks between the early 1940s and late 1970s because of a rapid turnover of breeders and long periods when there was no breeder (Schipprack & Mercer-Quarshie, 1984). Furthermore, when there were breeders in post they often needed to pay equal attention to several other crops at the same time. If that were not enough the sorghum breeder had very little back up, and had to be his own entomologist, plant pathologist and soil scientist.

Initially there were two sub-programmes: one for tall long-season types and another for short-season dwarf types. Major problems identified with the long season varieties were sorghum midge, head smut and stem borers. In the early 1950s, a long-season variety resistant to midge was identified but rejected by farmers because of its poor food quality. Dwarf short-season varieties introduced from the USA were high yielding (4 Mt ha^{-1}) but had poor grain quality, and were prone to head moulds (Anon., 1994a). They were rejected by farmers who continued to cultivate their local low-yielding varieties. Several experiments carried out to study the effects of different planting dates with one such short season variety, Hegari, led to declining yields, that were attributed to several factors, including shoot fly attack and the declining nitrate status of the soils. It was therefore concluded that the dwarf short-season varieties had no immediate value for the local farmer.

However, in 1969, a high-yielding short-season variety, named Naga white, was developed through mass selection from a collection made in Ghana. Following the development of Naga white, the focus of the breeding programme changed and new objectives were set to combine desirable traits of the dwarf, short-season types with those of the tall, late season types through a hybridization programme. Successful crosses were achieved by 1972 but, regrettably, the departure of the sorghum breeder without a replacement led to a loss of these crosses from which superior varieties might have emerged.

In the late 1970s, sorghum research received support from the German Government and this enabled the research programme to be expanded. Technical collaboration was also established with the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and the West African Sorghum Improvement Programme (WASIP). This enabled exotic germplasm to be sourced from ICRISAT and new objectives were set when a new breeder came on the scene. This was because of the need for an early, high-yielding variety with better grain quality and storability than Naga white, for the Upper regions and parts of the Northern region where the rainy season is shorter in duration. Finding none of the ICRISAT materials superior to Naga white, another hybridization programme was undertaken to improve the grain quality of Naga white (NAES, 1984). This time the hybrids obtained were superior with regard to yield potential, but the gain was possible only by using much higher inputs than commonly used by farmers. They could not be cultivated without insecticides. It was decided that the introduction of hybrids could not be recommended, "considering farmers' usual crop management practices, fertilizer levels and resources required for seed multiplication *vis-à-vis* the low importance of sorghum as a cash crop in northern Ghana" (NAES, 1984).

Attention then turned to the ICRISAT testing programmes and to developing sorghum genotypes with the following objectives: (1) late varieties of reduced height, increased grain yield and acceptable grain quality for the Northern region; (2) medium varieties of good yield potential of both grain and stalk and with good grain quality for the Northern and Upper regions; and (3) early, high-yielding varieties with acceptable grain quality and resistance to shoot fly, head bugs and grain moulds for early planting in the Upper region and late planting in the Northern region. But the results of these efforts showed the limited fitness of the germplasm for northern Ghana. The most outstanding problems were infestation with grain mould of genotypes (such as Naga white) that had erect and compact heads.

In 1991, an external evaluation of research at the research station concluded that the research agenda and methodology had not resulted in technology which was useful to farmers (Albert *et al.*, 2000). Particular reference was made to problems with the dissemination of new crop varieties. A radical change in the research approach was suggested, and the farming systems approach was proposed and adopted at the institutional level in 1993. Presumably, this shifted the philosophy underlying the breeding programme from focusing on yield increase as a principal measure of success to other characteristics. Three years after the introduction of the farming systems approach, one variety (Kapaala) was released. Although it was reported to have desirable grain characteristics for food and the local beverage, problems with head bug infestations and grain moulds compelled breeders to pursue further improvement of the variety.

From the 1940s to date, the sorghum improvement programme, through continued selections of promising lines on-station and on-farm trials, hasresulted in the release and/or recommendation of seven varieties, two of which have local origin.

Private sector interest in sorghum

In Ghana, the brewery industry started to show interest in sorghum during the 1980s when investigations were made into the possibility of using sorghum malt as a substitute for barley malt in the production of lager beer. Although experiments proved successful, the lack of local sorghum varieties with suitable grain quality, or suitable introductions well adapted to local conditions, caused this interest to wane. Renewed efforts to find suitable varieties yielded results when Kapaala, released by SARI, was found to have good malting properties. The breakthrough led to the decision to source sorghum locally as a partial replacement for barley malt. For the breweries it meant a saving in foreign exchange. From 2001–2004 several efforts were made to contract farmers in the three sorghum producing regions to produce sorghum via out-grower contract farming schemes, but with little success. The thesis will later explore the reasons, and show how a convergence of sciences approach might help ease some of the problems of sorghum contract farming.

General problems of sorghum

Sorghum production faces several constraints including a lack of suitable improved varieties, insect pests and diseases (midge, head bugs, *Striga*, stem borers, smuts and grain moulds), incomplete understanding of farming systems by researchers, poor soil fertility, financial limitations of farmers in purchasing agricultural inputs, and a shortage of scientists (Atokple, 1993). Under the National Agricultural Research Strategic plan for 1995 the following research priorities were identified for sorghum: development of varieties suitable for each ecological zone (including hybrids), variety development for brewing types, varieties with pest and disease resistance, and local germplasm collection (Anon., 1994b).

Though variety development has been top of the agenda of scientists for so long there is scant evidence that much has been achieved with regard to adoption of improved varieties by farmers. Low adoption of improved varieties (Jatoe *et al.*, 2005; Terborbri *et al*., 2001) and continued cultivation of local varieties have been identified as some of the causes of low yields in farmers' fields (Atokple, 1993, 1995). Dakurah *et al*. (1992) found that 80% of the red sorghums planted by farmers in northern Ghana were local varieties. Adoption levels of between 4.6% and 15.8% were reported (Terborbri *et al*., 2000) in the Upper East region and where higher levels (40%) were found, the average estimated areas cultivated with improved varieties were less than 5% of the total sorghum area (Jatoe *et al*., 2005). Low adoption was attributed to poor grain quality, requirement for high inputs, susceptibility to head bugs and grain moulds and poor research-extension-farmer linkages (Atokple, 1993; Jatoe *et al.*, 2005; Shipprack & Mercer-Quarshie, 1984; Tanzubil, 1993; Terborbri *et al*., 2001). However, breeders consider the low input production environment in which sorghum is grown a serious constraint to the adoption of improved varieties by farmers. They are of the opinion that under such low input environments plant breeding cannot be expected to have much impact at the farm level (Atokple, 1993). This may suggest that more attention should be given to varieties that have been maintained and grown by farmers over the years. There is however very little knowledge about farmers' varieties, their potential for improvement, and why and how they have been maintained.

Past collections from 'external' sources have mostly proven poorly adapted to local conditions (NAES, 1984; Shipprack & Mercer-Quarshie, 1984). Moreover, out of the recommended/released varieties, the improved local germplasm (e.g., Kadaga and Naga white) had relatively higher adoption levels than Framida, for example, which was introduced from South Africa. Although Framida is *Striga*-tolerant it has poor food quality and is very susceptible to grain moulds and headbugs (Frölich & Buah, 1991).

The unsuitability of introduced varieties for breeding programmes influenced the breeders' decision to rely more on local germplasm for future improvement efforts (Atokple, 1993). But at the same time the current collection of sorghum germplasm is still considered incomplete and it is lacking passport data (Rosenow, 2002). Some collections made in the past have been lost, due in part to rapid turnover of breeders, and with them, their associated (local) knowledge. Currently, there is very little knowledge about sorghum varieties grown by farmers, or how these varieties are used and are being managed. The informal sorghum seed system as a whole has received little attention even though there has been much research focus on farmer seed management practices for crops such as maize and cowpea (Lyon & Afikorah-Danquah, 1998; Tripp *et al*., 1987; Wright *et al*., 1995).

Research questions and objectives

The previous section on sorghum underscores the current problems and limitations facing agricultural research on sorghum. Sorghum is important for the poorest farmers in the country, for which reason research is required to make a useful contribution to those who depend on it most. The interest of the private sector in sorghum and the potential of sorghum to become an important cash crop give more reason to pay closer attention to the crop. However, the research sector, which could make the desired impact, seems relatively unable to do so. At the same time it is not clear how farmers are coping with identified limitations in their farming systems or what are their strategies for maintaining sorghum varieties in the face of poverty, small land holdings, low input production, poor rainfall and low soil fertility.

Undoubtedly research still has a major role to play in overcoming these limitations and helping farmers to make use of the small opportunities they have, but the question this analysis generates is "what is the most viable research route to follow?". Or, on what should research focus or what form of (technological) emphasis should be placed on the crop in order to respond to the needs of farmers? According to Weltzien *et al.* (2000) crop improvement programmes that are successful go beyond purely technical issues and the identification of specific breeding objectives. They should be guided by knowledge and an understanding of how each crop is managed and used within the entire farming system. What is more, the concerns expressed about the sub-optimal impact of research for small farmers in Africa, and the call for alternative pathways by which science can make a more useful contribution, suggest that neither the involvement of farmers nor their knowledge and research capacity should be left out of future research strategies. The CoS approach for conducting useful agricultural research seems to offer a potentially promising alternative, and this thesis explores how such an approach can become operational for the specific situations discussed above. Therefore the research questions for this thesis are as follows:

- How and in what area(s) can farmers and scientists effectively engage in agricultural research towards a sustainable use and management of sorghum genetic resources in Ghana?
- What lessons does the CoS approach provide for future efforts in designing and conducting research relevant for the conditions of small farmers in Ghana?

In order to answer these questions it is first necessary to understand how farmers manage these resources and what strategies they use. Based on the understanding that farmers' management of plant genetic resources is an integration of seed production, crop development and *in situ* maintenance embedded in knowledge, it is important to determine farmers' knowledge levels and skills associated with management in order to know how to effectively bring farmers into the research process.

The specific objectives are as follows:

- To determine how farmers use and manage their sorghum varieties and the factors that influence their management of diversity.

- To determine the genetic diversity of the sorghum varieties used and managed by farmers.
- To determine farmers' knowledge and practices in seed handling and diversity management in order to strengthen their capacity for variety maintenance and seed storage.
- To explore how, under market-driven conditions for sorghum production, new roles and relationships can be created and sustained among researchers, farmers and the private sector (as multi-stakeholders).

Working hypothesis

Given that farmers are continuously involved in a process of experimentation as part of their practices for managing crop genetic resources – actively testing new crop types and different ways of managing their crops, by trial and error, and comparing the performance of different plant types – scientists can work together effectively with farmers as co-researchers in the farmers' environment to support farmers' efforts if a framework of joint experimentation based on a scientific mode of inquiry is adopted.

Research methodology

The general research methodology used is that of the Convergence of Sciences approach. It is a process approach to agricultural technology development starting from a joint problem analysis, through to designing and implementation and then moving to analysis and evaluation (Anon., 2001). Unlike the structural approach involving a blue print which has a well calculated set of outcomes (Bartlett, 2004), CoS seeks to pay greater attention to processes and the interactions occurring across an entire research-application spectrum.

Technographic and Diagnostic studies are used as methods in the process of problem identification and analysis. Field experimentation is used during the implementation stage while analysis and evaluation are achieved through analysis and critical reflection. The specific tools employed at each stage are clearly outlined in the methodology sections in Chapters 2–7 of the thesis.

The methodology also makes use of diverse methods and combines both quantitative and qualitative social science methods as well as bioscience methods in the data gathering process, analysis, and interpretation of results. A survey is used to gather data on farmer variety use and management, while agronomic field trials and molecular marker techniques are used to determine genetic diversity.

Technographic study

Technography (Richards, 2001) was used as a first step in problem identification through the exploration of the innovation landscape for the crop (sorghum). The study looked at the technological histories, institutions, stakeholders, and contextual factors surrounding the crop. Technography is used as one of two approaches to making explicit pre-analytical choices (Röling *et al*., 2004) for further examination and development in the next steps of the research (in this case, the diagnostic study). The technography was carried out prior to this PhD research and the results provided the background and entry point for the diagnostic study, and subsequently the PhD research.

Diagnostic study

A diagnostic study was the second step in problem identification and was used primarily clearly to define the research problem to be tackled and ensure that the research was anchored in the needs, opportunities and realities of farmers (Van Schoubroek, 1999; Röling *et al*., 2004). It entailed making explicit pre-analytical choices with the participation of farmers and other research beneficiaries in order to define research priorities (Giampietro, 2003 cited in Röling *et al*., 2004). Such choices include the choices made in a research proposal and all other choices that are made before any participatory research with farmers begins. The results of the diagnostic study also enabled the definition of the research objectives for this thesis, while ensuring that issues considered relevant for farmers were addressed with their active participation in the research process. It is therefore important to point out that although, in the thesis, objectives are presented before the diagnostic study, the objectives were in fact derived from the results of the diagnostic study.

Experiments

Experiments were carried out during the implementation phase of the research to develop and test – with farmers – ‘technological options’ identified during and after the diagnostic study. It also entailed a process of negotiating, defining, and adapting experimental protocols with farmers as the major stakeholders and partners in the research.

Analysis

Analysis was undertaken throughout the various stages of the research and also at the end. In addition to employing qualitative and quantitative methods, reflection on the research processes itself formed an important part of the analysis.

Organization of the thesis

In Chapter 2, the opportunities and needs of sorghum farmers are identified using a diagnostic study. Choices are made for the type of research considered useful for farmers by assessing farmers' constraints in the production, management and use of sorghum diversity and by assessing their level of knowledge about plant variation and diversity management. In this chapter the determination of specific issues for investigation, the study area and the study villages are described.

Chapter 3 discusses in detail farmers' management of diversity for sorghum. It describes farmer variety portfolios, variety selection criteria, seed selection criteria, and seed storage practices. It also determines the factors that influence the management and maintenance of sorghum diversity by farmers.

In Chapter 4, the agro-morphological diversity of sorghum varieties cultivated by farmers in the study area is determined. Molecular techniques are also employed to determine the genetic diversity among sorghum germplasm cultivated in the area and within panicles of selected local varieties. The result of the molecular analysis of variation within varieties supports the need for research focused on enhancing farmers' practices in diversity management.

Chapters 5 and 6 explore the idea of 'converging' farmers and scientists using a joint experimental framework to investigate the phenomenon of plant variation, with an ambition to co-construct knowledge to strengthen farmers' skills in managing diversity. In Chapter 6, the same kind of science-based experimental framework is used to engage farmers and researchers in interactive research to evaluate seed storage practices and methods used by farmers in the two study villages, in order to determine their effectiveness for maintaining physiological seed quality (germination). Both chapters offer conclusions on how to do science-based action research with farmers.

Chapter 7 looks at CoS within a different setting – attempts to involve small-scale sorghum farmers in private-sector contract farming. Using a case study approach the chapter analyses technological and institutional problems leading to the failure of a contract farming venture, and suggests how researchers, farmers, NGOs and the private sector – as important multi-stakeholders in the management of sorghum genetic resources – can develop a shared research agenda to improve technology, so creating a viable contract farming arrangement for sorghum production. This chapter brings home that technology development is a multi-stakeholder process involving more than farmer-scientist interactions. The case study attempts to show that CoS can be the right kind of approach to embed technological improvement within market-led farming initiatives.

Chapter 8 is the concluding chapter. It summarizes the main findings, reflects on how the principles of CoS have been applied in this thesis, and reflects on some related outcomes. Lessons are summarized and suggestions made on how to better design interactive research with farmers.

CHAPTER 2

Assessing production constraints, management and use of sorghum diversity in north-east Ghana: A diagnostic study*

C.Y. Kudadjie[1, 3], P.C. Struik[2], P. Richards[3] and S.K. Offei[4]

[1] Agricultural Extension Department, College of Agriculture and Consumer Sciences, University of Ghana, P.O. Box 68, Legon, Ghana.
[2] Crop and Weed Ecology Group, Wageningen University, Wageningen, The Netherlands.
[3] Technology and Agrarian Development Group, Wageningen University, Wageningen, The Netherlands.
[4] Department of Crop Science, College of Agriculture and Consumer Sciences, University of Ghana, Legon, Ghana.

Abstract

This chapter reports on the results of a diagnostic study conducted to assess the problems and needs of sorghum farmers with the aim of determining the type of research that would be useful for them in their own context. The importance of the crop and its position within the cropping system are identified. Sorghum is still an integral part of the livelihoods of farmers. The crop is very versatile and not only contributes to food security but also plays a part in the socio-cultural, socio-economic, and religious aspects of the lives of farmers. Farmers have different uses for the varieties they grow, which depends on the morphological, agronomic and gastronomic traits of the crop. Sorghum varieties introduced from the research institutes have several problems including lodging, poor grain quality, bird damage and precocious germination. Farmers have developed management strategies for dealing with some of these problems. Nevertheless, further work is required by breeders to make the varieties more acceptable to users. Sorghum production constraints identified include poor soils, erratic rainfall and pest infestation of seeds during storage. The diagnostic study suggests that because farmers produce their own seed, enhancing their ability to improve the quality of their seed would be of benefit to them. The study further underscores the importance and value of diversity for farmers. It also highlights their understanding of diversity, and management and use of variation in their agronomic practices. Areas identified for further research together with farmers aim at enhancing farmers' knowledge towards strengthening their practices in diversity management and improving seed storage practices.

Keywords: Farmers' knowledge, *Sorghum bicolor*, maize, seed management, biodiversity, variety.

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Introduction

Agricultural research has often failed to achieve the required impact for many resource-poor farmers especially in Africa (Anon., 2001; Chambers & Jiggins, 1987b). There is therefore a pressing need to look beyond the conventional research approach to find more effective and sustainable ways of making agricultural research more relevant for small-scale farmers. The Convergence of Sciences Project (Anon., 2001) advocates interactive science in which the research agenda is set and implemented through the systematic participation of all stakeholders. Interactive science suggests the need for an approach that will make research more useful for farmers in their own local context. To this end a diagnostic study has been developed as one of the ways of anchoring research in the needs and conditions of farmers. Röling *et al*. (2004) argue that anchoring research in the opportunities and needs of farmers is just as important as embedding the research in the context of the international scientific literature.

Although the concept of a diagnostic study is not new it is not yet a standard research tool. Here, we approach the topic systematically, based on partnership between farmer groups and biological and social scientists. In this study diagnosis is not only used to assess and understand farmers' problems and needs but also as an entry point for a PhD research project that continues with the active participation of farmers in addressing the issues they consider relevant.

The diagnostic study reported here is within the confines of the sorghum (*Sorghum bicolor* (L.) Moench) crop and the specific agronomic and socio-economic context in which it is grown. In Ghana sorghum is a staple food and forms the basis of the farming systems of farmers in the savannah zones. It is a very versatile crop and a major source of income and employment for many. The choice for sorghum was based on the results of the technographic study (for a description of its methodology see Richards, 2001) conducted in Ghana between January and March 2002 (Offei *et al.*, 2002). The study revealed sorghum to be a 'grass roots' crop largely cultivated by subsistence farmers. Until recently low priority has been given to the crop and it has received comparatively little attention in the national research institutions, when compared with cereals like rice and maize. However, in the private sector there is interest in sorghum and this, in turn, provides opportunities to raise the research profile of the crop.

This chapter first examines the importance of sorghum in relationship to other crops grown by farmers in the study area. It then outlines the importance of crop diversity by showing how it is used to meet different needs. The crop production constraints and problems associated with the varieties grown are also assessed. The chapter then continues with an analysis of the knowledge and practices of farmers in diversity use and variety maintenance. Drawing on the above, the chapter outlines the implications of the findings and the issues agreed and identified with farmers for further research. It concludes with reflections on the use of a diagnostic study to focus the research.

Material and methods

Choice of study area

First, exploratory visits were made to the Walewale District in the Northern Region and the Bawku East and West Districts in the Upper East Region of Ghana. The choice of these districts was based on sorghum production data and yield statistics obtained from the Statistics, Research and Information Unit of the Ministry of Food and Agriculture (MoFA). The purpose of the exploration was to visit some villages, interact with local sorghum farmers and people working directly with these farmers and identify villages/communities where the study could be conducted. Being the lead producer in terms of cropped area and yield, the Bawku East district was selected for further studies. Located in the Sudan savannah zone of the north-eastern corner of Ghana, the basis of its traditional farming system has been the production of sorghum and millet. The rainfall pattern is mono-modal and the rainy season normally lasts from May to September/October.

Selection of villages

In the Bawku District two villages were selected using the following criteria (see also Figure 1):

- Possible influences on the sorghum biodiversity as a result of introgression of genotypes from bordering countries like Burkina Faso and Togo.
- Proximity to a peri-urban and rural sorghum and malt market.
- The nearby location of an out-station of the Savanna Agricultural Research Institute.

Accessibility to the research station was considered necessary to facilitate future interaction between farmers and researchers during the experimentation phase of the research project. From a list of villages, using a list of dominant crops grown, both obtained from the MoFA office in the district, the villages Terago and Tesnatinga were selected. Inhabitants were predominantly Kusasi by tribe, but also included a mix of other ethnic groups such as Mossi, Busanga and Yanga.

Introduction to villages

The extension agent introduced the principal researcher to the chief of each village as a student who wanted to learn about sorghum production. The need to hold several discussions with farmers in order to know how best to work with them was explained.

Subsequently an introductory meeting with farmers was scheduled in each village to explain the purpose of the research and pave the way for future contacts.

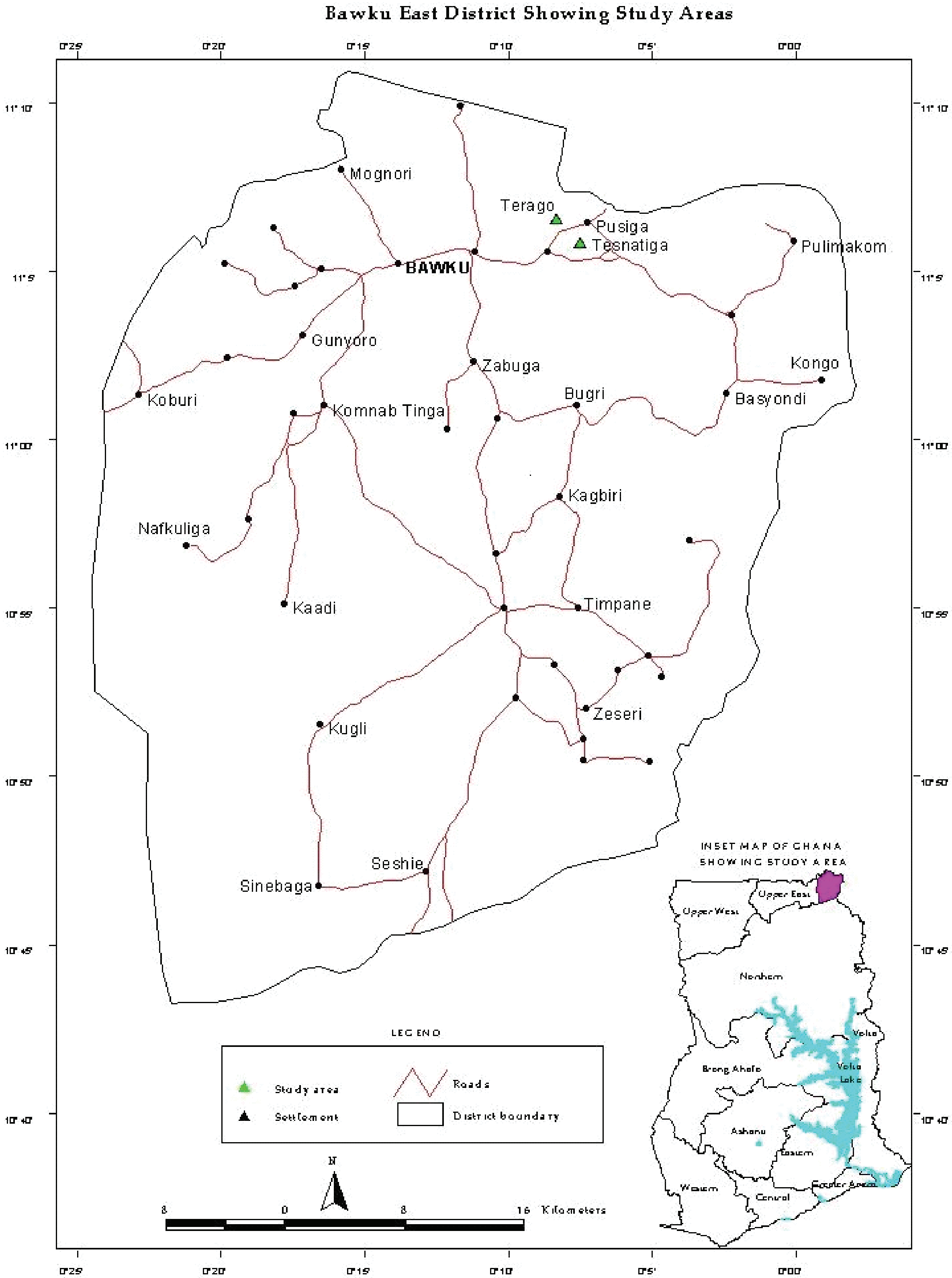

Figure 1. Map of Bawku East District, Ghana, with location of study villages.

Data collection

Community members from each village were asked to suggest representatives to serve as key informants on the following subjects: type of crops grown, cropping patterns, off-farm and income-generating activities, sorghum varieties grown and general information on the villages. The informants (8–10 per village) were required to have much knowledge about the village and the farming activities and included the young and old as well as male and female farmers. The information obtained from these informants was cross-checked and confirmed using semi-structured interviews, farm visits and field observations with other farmers in the same villages.

Subsequent data collection was done through discussions with different groups of farmers depending on the focus of the discussions. Different Participatory Rural Appraisal (PRA) tools were used as was deemed appropriate. Methods such as farmers' own classification of farmers and wealth ranking were used to understand the type of farmers living in the village. Using pair-wise ranking, two different groups of farmers representing large and small-scale farmers (according to farmers' own categorization) were used to determine the importance of the crops grown. Information on source of varieties, names and their meanings, period of introduction and disappearance was obtained with the aid of a history line drawn by farmers. Problems and constraints in sorghum production were identified through brainstorming sessions with farmers, a process that was facilitated through the use of a problem pyramid. This visual tool helped farmers with little or no formal education to prioritize the problems identified and establish a hierarchy. The most important problem was represented by the longest rectangle and the least important by the shortest. The rectangles were then arranged to form a pyramid starting with the longest at the bottom to the shortest at the top. Forty farmers from each village were individually interviewed on the main cereals they grew and on the functions of these cereals within their local household food security system. These farmers were also interviewed on the level and use of sorghum diversity.

Information sourced from other stakeholders such as seed growers was obtained mainly through semi-structured interviews, while group discussions combined with brainstorming sessions were used for the staff of MoFA.

Results and discussion

Importance of sorghum

Relative importance of sorghum

Several crops are grown in the area, including cereals (millet, maize, sorghum and rice), legumes (groundnut and cowpea), root and tuber crops (sweet potato and frafra potato (*Solenostemon rotundifolius*), and exotic and indigenous vegetables. Generally rice and sweet potato are grown for the market while the other cereals are consumed as food and form the main part of their diet. Table 1 shows how two groups of (larger and small-scale farmers) in the villages ranked maize, millet and sorghum based on their importance for food and cash income. As the order of importance did not differ between the two groups, only the overall average is presented. The importance of these crops for food was negatively, but not significantly correlated ($R^2 = 0.25$; n = 5) with their importance for cash, and the rank correlation (Spearman's ρ) was also not statistically significant ($P > 0.05$).

Early millet ranked first in importance for food but was less important as a cash crop. It is considered a traditional crop which is grown for food by every household and only sold as the last resort in times of dire need. It is always the first crop to be harvested after the long dry season when many households are already running out of food. So it is regarded as a hunger breaker. According to the farmers, sorghum would have ranked second, but the introduction and adoption of maize about 10 years ago changed this considerably. Although a few farmers in the region grew yellow maize before the early 1990s, it was not processed but eaten boiled or sold in its fresh state at the local market. During the same period early-maturing sorghum varieties (Naga white and red) cultivated by farmers were poor in terms of food quality and, in the case of Naga red, better suited for the production of local beer. The introduction of a short-cycle maize variety along with the provision of inorganic fertilizers supported by Sasakawa Global 2000 (SG 2000; a non-governmental organization), met with wide acceptance from farmers who found it suitable for preparing their local food. They also discovered that more flour was obtained from maize than from the same quantity of sorghum. The maize was early, high yielding and matured before their local sorghum, but the major drawback was the cost of fertilizer when the credit scheme through which the fertilizer was provided, ended.

The high ranking of maize for food and cash indicates that it fits farmers' needs for cash crops and for food security crops (Table 1). According to the farmers interviewed, maize and early millet are equally important as a crop grown for both home consumption and the market. Of the two traditional crops (millet and sorghum), millet is more important for home consumption than sorghum, and so is maize. Home consumption includes food and any other dietary function. Except for early red sorghum, which is mainly processed into a local alcoholic beverage (*pito*), all cereals are used as food. The late sorghum has dual function and may be regarded as the subsistence crop par excellence for half the number of farmers interviewed.

So sorghum appears not to be a front-line food security crop or a top-ranked cash

Table 1. Millet, maize and sorghum ranked in order of their importance as food or cash crop, and function of the crops as indicated by the farmers in the study area.

Crop	Importance[1]		Crop function[2] (response by farmers, %)			
	Food	Cash	Consumption	Market	Consumption & market	Other
Early millet	1	4	67	3	30	0
Maize	2	2	54	14	31	1
Late millet	3	5	56	14	28	2
Late sorghum	4	3	49	3	5	43
Early red sorghum	5	1	47	17	16	20

[1] Based on group discussion.

[2] Based on interviews with individual farmers.

crop. One major reason for this is the lack of early sorghum varieties that are suitable for food. But in view of the fact that it still holds a consumption function for half the number of farmers interviewed it may be considered as a substitute food security crop. Furthermore, the relatively high ranking of the early red sorghum and late sorghum on importance for cash suggests that sorghum still has a significant place on the local market. The diagnostic study indicates that sorghum is a salient crop, but after interaction with farmers, and with the benefit of hindsight, it is possible to argue millet might have been an alternative, or even better focus.

Naming, use and diversity of sorghum

Naming of sorghum varieties

The farmers mentioned several sorghum varieties that had been grown in the villages over the last 60 years. Varieties had been named according to the source, the person through whom it was believed to have been introduced or its use. Names such as *Eyadema* (the then president of Togo) indicate the origin of the variety, and farmers explained that the seeds were first obtained from Togo. *Kapaala* (new sorghum) and *Eyadema* were used interchangeably by some farmers because they both are early maturing, have the same plant colour, panicle architecture and grain colour. There is reason to believe that *Eyadema*, such as *Kapaala*, is an ICRISAT (International Crops Research Institute for the Semi-arid Tropics) variety known as ICSV111 introduced into several West African countries some years ago.

Other names like *Widki* (horses' millet) and *Niyinrinchi* (your eyes will not turn) explain how these varieties are used: while in the past *Widki* was fed to horses because it was considered to be of poor quality and unsuitable for human consumption, *Niyinrinchi* is valued for its medicinal value and used as an antidote for dizziness. Three early, red sorghum varieties (*Kokosbog, Gurudu and Zula*), similar in plant colour and seed colour were known collectively as Naga (no known meaning). The most commonly grown local, long-cycle varieties, collectively known as *Belko* (meaning not known), consisted of different types that were named after their grain colour and endosperm texture.

In Mali, Chakanda (2000) also found origin and function to be important elements in the naming of sorghum varieties. The second most frequently mentioned criterion used by farmers in Mali in naming their sorghum varieties was the origin followed by the function of the variety cultivated.

The use of collective names sometimes indicates a farmers' system of classification based on some agronomic or morphological characteristics. For instance studies by Abidin (2004) on sweet potato varieties in north-eastern Uganda revealed that some vernacular names used by farmers provided important information on maturity period, yield performance and other yield-related information.

It has been suggested by McGuire (2002) that the names Ethiopian farmers assigned to sorghum types described variants within groups or distinguished a sub-type or local population. A comprehensive understanding of the farmers' system of classification using their naming system and descriptions would be useful in explaining local conceptions and perceptions of a variety, and is a subject for further investigation.

Sorghum varieties grown

The farmers in the two study villages grew early-maturing and late-maturing sorghum varieties. The main early-maturing varieties were Naga white, Naga red and Eyadema/Kapaala; the main late varieties belonged to the Belko type. Thirty-five percent of the farmers grew improved varieties introduced from research, i.e., Naga white and Eyadema/Kapaala while 55 and 74% grew Naga red and the Belko types, respectively. Reasons given by farmers for not cultivating Naga white included poor taste and food quality, poor storage and its requirement of fertile soils, while reasons for not growing Kapaala were its requirement of additional inputs (such as fertilizers), lack of seeds and insufficient land. Not growing Belko was mainly due to its low yield and late maturity. Some farmers perceived that the rainfall pattern had changed to the extent that late-maturing varieties are no longer adapted to the prevailing conditions. Farmers who did not grow Naga red attributed this to insufficient land. Such farmers hired land at high costs. They, therefore, preferred to cultivate crops such as groundnuts because they fetched almost twice the amount of money on the market.

Use of sorghum varieties

Table 2 shows how the different varieties are used. The value of these varieties was linked to the social, economic, cultural, traditional, religious, food security, nutritional and health aspects of the farmers' lives. Varieties such as Naga red and Belko have several uses, which explains why many farmers grow them. Being the raw material for the local beer it is impossible to separate sorghum from the social, cultural and religious events that help to maintain and create new social bonds. Farmers mentioned that some varieties have been lost through famine or calamities. They also complained that other ones (*Kerig, Gibrok and Niyirinchi*) are low yielding, late maturing and not well suited for the changing environmental conditions. Nevertheless conscious efforts are still made to grow them year after year in very small areas, in an attempt to preserve them. This is not surprising considering their importance for particular needs such as feeding lactating mothers, curing illnesses and providing delicacies for guests.

Diversity of sorghum varieties

Diversity in growth period, plant architecture, palatability of grain and leaves for humans or animals were all found to determine the value placed on the different sorghum varieties. The fact that farmers are still holding and using these varieties implies that they recognize the need to maintain this diversity and that they have developed strategies and skills for adapting their germplasm to the changing environmental conditions and their own specific household needs. These skills need to be built upon, and establishing links between formal and local crop development may be one way of doing so. Clearly, these skills, when developed or enhanced will be indispensable for improving the livelihood of farmers.

The culture, tradition, customs and religion of these farmers had strong ties to these varieties. *Belko*, for example, is believed to have originated from the ancestors and is entrusted to each generation for passing it on to the next. Failure to do so will incur the displeasure of these ancestors, who are held in high esteem and considered the source of blessing and prosperity. Similarly, all ceremonies, celebrations and rituals that require food preparation or libations to invoke their blessing must of necessity use this variety. All natives of the land must ensure that it is cultivated each year for such purposes. By this practice such varieties are not likely to become extinct because farmers will continue to conserve and adapt them to their changing conditions.

Millar *et al.* (1999) draw attention to the relationship between spirituality and agriculture among small farmers in northern Ghana. They found that in northern Ghana the worship of the ancestors is central in the worldview of the rural people. The traditional crops (sorghum and millet) were received from the ancestors. The spirits of the ancestors are owners of humankind and responsible for their well being. Rituals are,

Table 2. Uses and plant parts used of sorghum varieties by the farmers in the study area.

Use	Plant part used	Commonly used varieties
Beverage	Grain	Gurudu (Naga red)
		Belko (Nwuago)
Building/fencing material	Stalks	Belko (all types)
		Naga red
Cash income	Grain	Kapaala
		Naga red
Culture (festivals, marriages, celebrations, traditional ceremonies and rituals)	Grain and stalks	Belko (peleg)
		Belko (all types)
Famine/hunger crop	Grain	Naga red
		Naga white/Widki
Animal feed	Leaves and stalks	All available varieties
Food	Grain	Amenyeaw
		Abiemlad
		Akpaa
		Belko (Piele, Zia, Nwuago)
		Gibrok
		Kapaala/Eyadema
		Kerig
		Torok
Fuel	Stalks	Belko
		Naga red
Medicine (cure for diarrhoea, antidote for dizziness)	Grain	Naga red
		Niyirinchi
Religion (sacrifices for pacifying gods)	Grain	Belko
Special foods (desserts, food for lactating mothers)	Grain	Gibrok
		Amenyeaw

therefore, associated with such crops but to a far less extent to crops introduced from outside.

Farmers' production constraints

Table 3 lists the problems encountered by farmers in growing sorghum.

Table 3. Sorghum problems in the study area, ranked by the farmers in order of importance.

Ranking	Problem
1	Insufficient rainfall
2	Delayed rainfall
3	Infertile land
4	No bullocks for ploughing
5	Insufficient seed
6	Termites attack seed in storage
7	*Striga* infestation
8	Black ants

Rainfall

The erratic nature of rainfall is a major problem for farmers since their agriculture is typically rain-fed. Farmers were of the view that the amount of rainfall has decreased and is insufficient. However, it appears that the problem stems from the lack of appropriate sorghum varieties that fit the current rainfall regime rather than the rainfall regime itself. Findings from a study conducted in the Upper East Region (Anon., 2000) showed that there has been no significant decrease in the average monthly rainfall for Bawku for the period 1976–1999. Comparing the periods 1946–1986 and 1976–1999 for the average annual rainfall in Bawku even indicates an increase over the latter period. These findings suggest that the farmers' perception about diminishing rainfall may be because of a reduced water-holding capacity of their soils, related to loss of soil organic matter.

Farmers also explained that a delay in the onset of the rains delayed planting so that their local varieties, which were late maturing, ran the risk of failure. Under such circumstances only short-cycle varieties and crops, such as short-cycle maize, could be grown. Such a situation could gradually lead to a loss in diversity.

Soil quality

Poor soils were a source of worry for all farmers. Although few use inorganic fertilizers for growing sorghum it is common for farmers to improve their soils with organic or farmyard manure depending on the possession of livestock. Apart from the rich who possess a large number of cattle, for most households the quantities of farmyard manure are small and must be shared among all male members of the household who own farmland. A common feature of the local farming system is that a continuously cultivated farmyard surrounds each compound. In addition to this, most farmers also cultivate one or more bush farms, within easy reach (i.e., between 1–3 km from the compound). The farmyards are used for growing food crops for home consumption and are controlled by the male head and his married sons. Farmyard manure is applied on a rotational basis so that different portions of land receive inputs each year. But it is the soils around the compound and the land cultivated to crops such as maize and millet that receive the most attention. Farmyard manure is hardly used on bush farms. So women, who are often allocated portions of the bush farms, are always in a disadvantageous position. Farmers attribute the low fertility of their soils to population explosion, land fragmentation, land scarcity, and continuous cropping. They feel that not much could be done except to try to control practices such as ploughing along the slope, and reduce destruction of organic material resulting from burning during the dry season.

Lack of bullocks and seed

Lack of bullocks delayed planting, particularly for farmers who could not afford to hire them. They could only borrow bullocks after their owners had finished using them. This means that the first few rains, which are important for land preparation and sowing, would be missed and crops/varieties that require early planting cannot be grown.

Shortage of seed usually occurred when farmers were forced to consume grain reserved for planting. Pest infestation of stored seeds also led to shortage of planting materials. Farmers without adequate seeds for planting solicit for seeds from friends or family members, buy from the market or provide labour to other farmers in exchange for seeds. Farmers acknowledged that seed from the market was not always of good quality but that they had to use it because there was no other source of supply.

Pests

Stored early millet and Naga red sorghum were reported to be very susceptible to weevils because they have softer grains, whereas sorghum varieties of the Belko group have harder and more resistant grains. To combat termites some used chemicals bought from the market or wood ash to protect their seed while a few grew plants believed to be repellent to pests, around their storage barns.

The farmers in the study area did not consider *Striga* as a very important pest as clearly indicated by its position in Table 3. It was not considered to be a problem in early-maturing crops and was controlled by weeding or hand pulling. Farmers explained that the problem of *Striga* was only severe where a long cycle sorghum variety such as Belko was grown without weeding consistently.

In the event of a long dry spell, insects such as black ants tend to remove seeds from the soil immediately after sowing and infilling becomes necessary, which is an added cost to the farmer. Farmers have tried to prevent this problem by seed dressing before planting but this has often proved to be detrimental because fowls pick up the treated seeds and are poisoned.

Impact on farmers' choices

Problems with rainfall and soil fertility are likely to influence farmers' choices between the sorghum varieties to be grown and so affect diversity. Depending on the rainfall regime in a particular year less or more early or late-maturing varieties will be grown. Similarly, the fertility status of the farmer's soil would determine how much land is allocated to each variety.

Apart from the problems outlined above, problems more specific to the sorghum varieties used by farmers were reported. These included poor adaptation to the soils, lodging, bird damage, poor taste and grain quality and precocious germination. Farmers have developed some management strategies to deal with these problems.

Varieties susceptible to lodging are fortified when they start booting by reshaping the ridges to give support to their roots. Varieties prone to precocious germination are harvested immediately they mature (to avoid being beaten by the rain), and well dried. Varieties with poor grain quality may be cultivated in small areas or not at all. Their grain is often mixed with larger quantities of higher quality grain for food preparation. Where a variety requires very fertile soils, farmers apply farmyard manure or compost to their lands. But in the absence of such inputs they are not cultivated at all. Farmers plant varieties that are susceptible to bird damage close to their compounds or resort to bird scaring if they are planted further away. Farmers who have enough land cultivate large areas and try to ensure that their planting dates coincide with those of other farmers in order to reduce the damage caused to a single isolated farm. The development of such strategies indicates the willingness and innovative capacities of farmers to manage their varieties.

Farmers' knowledge and practices relating to biodiversity, seed management and variety maintenance

Variation and diversity management

Discussions with farmers and observations in farmers' fields during seed selection revealed that farmers have knowledge about diversity and seed management. On their fields farmers appreciated diversity, using characteristics such as plant height, panicle shape, panicle length and compactness, tillering and seed colour as descriptors or markers. While some were keenly aware of variation within populations others were not or did not consider it to be important. In a discussion with 23 farmers from the study villages, over 50% of the farmers confirmed that they sometimes observed differences within fields sown from the same seed lot, while others maintained that differences do not occur. Farmers also showed some knowledge about the predominantly self-pollinating nature of sorghum by comparing it with maize. They explained that little cross pollination was seen in sorghum, whereas maize fields close to each other consisted of several mixtures, which they attributed to “the wind blowing flowers from maize plants in one field to the other”.

Variation within populations was attributed to rainfall, land and nature. This may be interpreted as genotype × environment interaction. Though farmers could discuss some of the factors that influence variation, their explanations suggested that they did not fully comprehend how it occurred, or what the sources were of this variation. For example, differences in seed colour of plants from the same parent were attributed to insufficient washing of panicles by rainwater during seed ripening. As explained by Van Dusseldorp & Box (1993) the worldview of cultivators, which is often different from that of scientists, leads to differences in causal explanations of what happens in the environment.

Usually, varieties are not planted in mixtures. However, some farmers plant sole crops of a single variety with another variety just along the borders, while others plant their Belko types in mixtures. These border plants tended to be varieties reserved for medicinal or other specific purposes for which no large quantities of grain are required. Roguing was not practised although off-types were observed in some fields at maturity before harvesting. A few farmers attempted to maintain the purity of their seeds at the time of harvesting by selecting panicles with grains that looked exactly like what they had planted. Others were not interested in purity but in yield and therefore selected panicles only from high-yielding plants even though they did not look like the original, hoping that the subsequent crop would portray the same characteristic, i.e., good yield. These are different selection practices which could give different results, but what farmers were unaware of is how these different practices could contribute to or influence the variation in their fields.

Varieties and soil type

In deciding where to plant sorghum, farmers matched varieties with soil types. Information from farmers revealed that the varieties Naga white and Kapaala require fertile soils to do well and therefore are planted either close to the compound where a lot of organic manure is added to the soil or at other places considered fertile. Belko is planted on less fertile soils although it is common to see small plots of Belko planted close to the compound. The Naga red types have different soil requirements; although Gurudu and Zula can be grown on different types of soils they perform better in valley bottoms or soils with a high moisture content. On the other hand, Kokosbog requires well-drained soils and is therefore planted on upland soils and not in valley bottoms. Although these claims have not been tested to ascertain their validity, they still indicate that farmers believe varieties of even the same crop may have different soil requirements and therefore must be managed differently.

Seed management

Seed material was collected by selecting panicles in the field immediately after harvesting (cutting down stalks). Panicles must be large and have large grains free from disease. Panicles with small grains are rejected. Poor germination was associated with insect-infestation, mouldy or diseased grains. The practice of winnowing before planting was believed to rid the seed lot of seeds that would not germinate. Storage methods included hanging the selected panicles from the roofs of storage barns made from grass or mud, in the open or close to the kitchen smoke. Other farmers threshed the panicles and stored the seed in polythene or nylon bags. Though farmers believed that these storage methods were quite effective in maintaining seed quality, the number of seeds sown per planting hole (6–8) suggests otherwise. When questioned, they explained that not all seeds germinate and since it is difficult to determine this before sowing it is necessary to sow many seeds and thin to the required number of plants later. Farmers lacked knowledge about the use of simple tests to determine the germination capacity of their seed lot. The diagnostic study thus suggests that because farmers produce and use their own seed, enhancing the knowledge and ability to improve the quality of their seed would be of benefit to them.

Pest and disease management

Pests and diseases of sorghum in the field did not seem to be of much importance to the farmers. In several cases where attention was drawn to insects such as mould-causing headbugs (*Eurystylus immaculatus*) seen on panicles in the fields, farmers insisted that "they do not affect the crop". Diseases like smut were believed to be caused by rainwater entering flowers when they open in the afternoon. Because its mode of transmission was unknown to farmers, proper measures (like roguing at an early stage) were not taken. Bellon (2001) observed that in farming areas where certain phenomena are difficult to observe, or that have interacting causal factors, farmers' knowledge may be less precise or even non-existent.

Farmers' perceptions about the technology development system and its products

The major responsibility of introducing, promoting and disseminating technology lies with the Extension Services of the Ministry of Food and Agriculture (MoFA). Agricultural Extension Agents (AEAs) are directly involved in introducing technology from research institutes to farmers and serve as links between researchers and farmers. The technology on sorghum that has been extended to farmers has mainly been in the form of improved varieties. Before the release of such varieties, these agents conduct adaptive trials with farmers and send feedback to and from research. Few researchers interact directly with farmers during this adaptive stage and most farmers have more contact with these AEAs than with researchers. It is for this reason that the views of both agricultural extension agents and farmers were considered important in this diagnostic study. The perceptions of seed out-growers are also considered.

In the Upper East Region, which includes Bawku East District, three varieties from Savanna Agricultural Research Institute (SARI) were introduced to farmers through MoFA. Naga white was introduced in 1988, Framida in 1990 and Kapaala in 2000. As the introduction of Naga white to farmers in the region was supported by supplies of fertilizers, its cultivation took off quite well and yields obtained were very high, but the poor quality of the grain for food and the absence of a market for the crop soon discouraged farmers from growing it. Framida, an early maturing, red grained variety had the problem of shattering during harvest and also suffered from poor seed set due to its susceptibility to the sorghum midge. It is reported to have lost popularity very quickly. Although Kapaala was released in 1996 it was formally introduced in 2000 in the Bawku East district by MoFA.

During discussions with AEAs on their role in transferring sorghum technology to farmers they expressed their concern about the technology development system. The agents felt that farmer adoption of varieties was slow and low and that the weak linkage between farmers and researchers was partly responsible for this. They were of the opinion that the problems associated with the varieties like poor demand and lack of market discouraged seed growers, which contributed to the poor adoption. So they acknowledged that it was not just sufficient to provide technology (improved varieties) but that there also is a need to include other support systems like market outlets for such products. This is echoed by Röling *et al.* (2004), when they point out that there is a limit to which technology development becomes important for farmers if the opportunities provided by marketing, service and input delivery and financial institutions are not created.

The problems associated with the varieties as mentioned by AEAs, farmers and seed growers are shown in Table 4. Although their views were obtained separately several problems outlined for Naga white and Kapaala were commonly expressed by extension agents and farmers. These problems were: precocious germination, bird damage, high soil fertility requirement and lodging. It is not surprising that fewer problems were mentioned by farmers than by extension agents since the agents interact with a wider group of farmers than those contacted in this study. Farmers are more likely to mention only those problems that they consider important. However, this is not conclusive since the set of problems listed by extension agents were not presented to farmers for their comments. The variety Framida was not mentioned by farmers at all. Problems mentioned by seed growers only applied to Kapaala because it is currently the only sorghum variety the seed of which is produced by seed growers.

These growers belong to the Northern Seed Grower's Association (NOSGA) that forms part of the formal seed sector, which still is in its developmental stages. Seed growers started producing seed during the past 2–7 years. Their major problem was marketing. The demand for Kapaala seed was low and in the past, growers had to find their own means of selling the seed. Even though the recent interest of a brewing company (Guinness Ghana Ltd) in the variety Kapaala was seen by growers as a likely solution to their marketing problems, they pointed out that this market could be assured only if farmers would be willing to produce the grain. Yet, in the first year that the brewery contracted farmers in the Northern Region, only 10–12% of the target was achieved. This was attributed to headbug infestation of the grain, associated moulds, and poor drying, all of which reduced grain quality and therefore most of the grain was rejected. According to seed growers the prices offered to the farmers were too low, and

Table 4. Problems with sorghum varieties introduced by research institutions, as expressed by extension agents (A), farmers (F) and seed growers (S).

Problem	Variety		
	Naga white	Framida	Kapaala
Susceptibility to bird damage	A,F		F,S
Precocious germination	A,F		A,F,S
Susceptible to mould	A,F		F
Poor grain quality and taste	A,F		
Low suitability for preparing *pito*[1]	A,F		
Non-uniform ripening	A		
Stover of poor fuel quality	A		
Poor storability	A		A
Susceptible to lodging	A		A,F,S
Seed shattering		A	
Poor seed set (sorghum midge)		A	
Sweet stalks prone to stealing			A,F,S
Requiring fertile soils			A,F,S
Lack of market/poor demand			S

[1]*Pito* = local beer.

in view of the cost incurred for cleaning and transporting the grain it was considered better to sell on the local market. Growers were of the view that for this initiative to take off successfully, farmers would require support to offset the high cost of production.

The perceptions of farmers, seed growers and extension agents of the varieties introduced from SARI clearly indicate that further work by breeders is needed to address these problems and make the varieties more acceptable to all users of the crop.

Further research and agreements with farmers

The issues arising from the diagnostic study point to the need for developing appropriate research and development strategies that are based on the capacities of farmers to experiment with their crops and on the knowledge they have acquired in managing their diversity. The proposal for research with farmers is aimed at linking scientific knowledge to farmers' knowledge (De Boef *et al.*, 1993; Reij & Waters-Bayer, 2001). For such a linkage to be developed and sustained between the two knowledge systems, dialogue is needed in which both farmers and scientist are willing to listen to each other and learn from each other as equal partners in agricultural change. A form of dialogue that paves the way for learning and interaction between different knowledge systems has been adopted in determining the way forward for experimental work with farmers in the subsequent phases of the research.

The diagnostic study has led to the identification of an area of research which is not only based on what farmers know but also what they do not know. The knowledge of farmers in managing diversity and variety maintenance became apparent during several exchanges with farmers on their practices. Evidence of varietal mixtures and the presence of off-types in farmers' fields pointed to the need to understand farmers' appreciation and use of variation. The importance of variation for farmers, and the human and natural elements that contribute to the creation or maintenance of variation was discussed with farmers. Table 5 shows in summary form the different phenomena (genetic, environmental and temporal sources of variation) discussed with farmers. It provides a qualitative assessment of farmers' knowledge, understanding, use and management of each phenomenon in their agronomic practices. Based on this assessment a learning exercise on the identified phenomenon has been created with farmers and will be part of the rest of the research. On the learning plot designed with farmers different panicles of sorghum cultivars selected by farmers will be grown on a head-to-row basis. The exchanges between farmers and researchers will be aimed at augmenting farmers' knowledge on variation. It is expected that the knowledge gained will be used by farmers to strengthen their skills in managing their sorghum genetic resources. Through field experiments and observations, researchers and farmers will be also be engaged in learning about the morphological traits used by farmers to distinguish between varieties in order to understand farmers' concept of variety.

Following the diagnostic study continued dialogue with farmers on their seed management and storage practices showed that the different treatments used by farmers to store their seed were all geared to one main objective: to produce good

Table 5. Researchers' assessment of farmers' knowledge, understanding, use and management of variation, and the plans for further research on these aspects.

Source of variation		Farmers' knowledge				Research plans		
		Knowledge	Understanding	Use	Management	Identification	Investigation	Create learning experience
Genetic	Between variety variation	++[1]	++	++	++	+[2]	+	+
	Within variety variation	+	±[3]	–[4]	–	+	+	+
Environmental	Soil	++	++	+	+	–	–	–
	Weather	++	++	–	–	+	–	–
	Site-specific	++	+	±	–	–	–	–
	Plant to plant / random variation	±	±	±	–	+	+	+
Genotype × environment		+	±	±	±	+	+	–
Temporal	Outcrossing	++	+	–	–	+	–	–
	Selection	++	+	+	+	+	+	–
	Single panicle descent	±	–	–	–	+	+	+

[1] ++ farmers know or understand the phenomenon in detail and make use of it and manage it in their agronomic practices; the research project identifies the phenomenon extensively, investigates it in detail or creates an intensive joint learning exercise on it.

[2] + most farmers are aware of the phenomenon, understand it to some extent, make use of it and manage it to some extent; the research project pays attention to the phenomenon, investigates it to some extent and includes it in the joint learning exercises.

[3] ± some farmers, but not the majority, are aware of the phenomenon, understand it to some extent, make use of it and manage it to some extent.

[4] – farmers are not aware of the phenomenon, do not understand it, and are definitely not capable of using or managing it; the research plan is not dealing with it.

quality seed that will germinate at planting time. However, a lot of attention appeared to have been paid to preventing diseases and pests that destroy the seeds in storage and thus good germination was directly linked to pest- and disease-free seeds. Farmers were also aware that there were other aspects, such as moisture, aeration and temperature, that influenced the physiological seed quality and that these were important during storage. Over the years many farmers have changed from one treatment to the other in an attempt to obtain good quality seed but not much attention was paid to the storage method. This was the case for both sorghum and millet. It was, therefore, agreed with farmers to test and compare the effect of (1) treatments, and (2) storage methods on seed quality. The use of germination capacity as a test of quality was proposed and accepted by farmers as a measure of effectiveness.

Another important issue that emerged from the diagnostic study was the lack of appropriate, improved sorghum varieties for farmers. This view was shared not only by farmers and extensionists but also by seed growers. During the validation of the results of the diagnostic study with researchers, breeders, farmers, extensionists, seed growers and other relevant stakeholders it became evident that the problems with the varieties were being addressed. The breeders revealed that a hybridization programme to improve the qualities of the most recently introduced variety was already underway. Out of this programme some promising breeding lines had already been selected for further testing. These lines will be evaluated on-farm with farmers in different locations during the growing season. It is hoped that feedback obtained from farmers involved in the evaluation will provide useful information to shape breeders' efforts to make varieties more acceptable.

Reflections on the use of diagnostic study

Reflecting on the process of the diagnostic study, the principle researcher agrees that making certain pre-analytic choices such as choosing a specific crop is necessary to help delineate boundaries for the investigation and have an entry point for the research. During the investigation, however, these choices must not become limiting and/or reduce the scope of the diagnosis when it becomes necessary to broaden the scope. It should also be pointed out that studies of this nature demand adequate time at the disposal of the researcher to ensure that sufficient attention is paid to all issues that appear relevant. So if this approach is used for 'academic' research its full benefits may not always be realized. Perhaps the approach may be more useful in research for development, where time is not so limited as it is in a PhD programme.

In this study not all the problems identified with farmers could be channelled into the field research. The use of the diagnostic study as a precursor to further PhD work, however, did not compel the researcher to address all issues that came to light once there were other ways of addressing them. A specific case was the problem of low soil fertility expressed by farmers, which was ranked very high in importance. During validation of the findings with other stakeholders, it became clear that methods for assisting farmers to address the problem existed, but had either not been available to, or were not used by, this group of farmers. Subsequently, extension agents from MoFA contacted interested and willing farmers and arrangements for training in compost making are currently underway.

The initial stages of the data collection process of the study were very slow. This was due to the inability of the researcher to speak the local language and to the lack of expertise in riding a motorcycle, the main means of transportation in the area. For the first three months during which efforts were made to find a translator, an extension agent assisted with translation. The good services of the same agent had to be relied upon for transportation to and from the villages on motorbike. This meant that visits had to be planned outside his field schedule and at his convenience until such a time that the researcher gained enough confidence to ride. During this period very little time was spent in the communities with farmers outside the scheduled meetings. It is felt that otherwise a lot more information could have been gathered more quickly. This experience confirms that lack of familiarity with the culture and language of the people poses barriers to working effectively with them. Agricultural science for farmers in multi-ethnic communities will require either scientists from the area, or some of the linguistic preparation undertaken by anthropologists and other social science field workers.

Conclusions

Although sorghum has been known for many years as one of the most important and widely cultivated cereals for the people of northern Ghana, the diagnostic study revealed that its position might be changing for the farmers of Terago and Tesnatinga villages of the Bawku East district. Sorghum is still important and may be considered as a substitute food and cash crop. But the emergence of maize – which after millet has the advantage of being a short-duration crop contributing to coping with seasonal hunger in the area – is seen as one of the factors responsible for this shift in importance. Late-maturing crops are becoming less reliable and no longer adapted to changing and uncertain rainfall patterns. For some farmers, therefore, solutions to food security lie in early-maturing crops, both for consumption and the market. Although this greatly increases the opportunity for formal research to develop high-yielding and early-maturing sorghum varieties to fill this gap, the inappropriateness of such varieties developed in the past has limited their impact.

This generates the question as to whether a technological emphasis on sorghum in terms of the development of improved varieties should be pursued. Perhaps research efforts to promote sorghum as a food crop may go nowhere, while research for industrial use and commercial purposes might stand a better chance. However, answering this question goes beyond the scope of the present study. What the study does establish, however, is that despite environmental change sorghum continues to hold importance for many farmers beyond considerations of either food security or cash income. Sorghum is still very much an integral part of a local culture in which the ancestors continue to play a part. Apart from that, the diagnostic study brought to light the importance and value of genetic biodiversity. This appeared part of the motivation for farmers to join in a research effort intended to support and build on their own efforts and skills in biodiversity and variety maintenance. This sets the agenda for the experimental phase of the research.

CHAPTER 3

Sorghum variety use and management by farmers in north-east Ghana

Introduction

In arid and semi-arid parts of Africa, sorghum (*Sorghum bicolor* (L.) Moench) is one of the main staples of the poorest and most food-insecure people (FAO, 1996). Its versatility and ability to thrive in marginal areas makes it a very important crop. In hotter and drier regions, such as northern Ghana, particularly the Upper East region, sorghum is an important traditional and multi-purpose crop used and managed primarily by small-scale farmers.

The importance of plant genetic resources for world food security continues to sustain interest in the role played by farmers in managing crop diversity (Cooper *et al.*, 1992; Cromwell & Oosterhout, 1999; FAO, 2004). Farmers' management of diversity can be described in terms of the following variables: the number and types of varieties maintained, variety selection and adaptation, seed flows, seed selection and seed storage (Almekinders, 2000; Bellon & Brush, 1994; Jarvis *et al.*, 2000a). Farmers make decisions with regard to these variables during the process of management.

The number and types of varieties present in a farmer's field is a result in part of his/her decision to maintain, add or discard a variety in a growing season. Farmers have several criteria for selecting what, where, when and how to plant these varieties (Bellon, 1991; Bellon & Smale, 1998; Sperling *et al.*, 1993; Teshome *et al.*, 1999). These criteria may be categorized as the performance of a variety with respect to agro-ecological conditions (Almekinders & Louwaars, 1999; Bhuktan *et al.*, 1999; Demissie & Bjornstad, 1996); the performance of a variety with respect to management and inputs (Bellon, 1991; Zimmerer, 1991); and the performance of a variety with respect to purposes and uses (Louette *et al*., 1997; Weltzien *et al*., 1996). Farmers also select different crop types and varieties to adapt to their own local conditions based on a complex set of decisions determined by the needs and expectations of the individual, household and community. Different social groups of farmers within a community may use different varieties of the same crop, each tailored to optimize performance according to their own resource limitations (Friis-Hansen, 2000; Linnares, 1992; Longley, 1999).

Seed flows are an important aspect of farmers' diversity management and are the processes by which farmers obtain the physical unit of seed for a given variety (Bellon & Smale, 1998). Seed exchange and movement are important for understanding the diversity in a given location because they form the basis for incorporating new varieties and obtaining material that has been lost but is still regarded as desirable (Bellon *et al*., 1997). The flow of seeds among small-scale farmers occurs along various pathways. Within local systems, seed is acquired by farmers in four main ways (Almekinders *et al*., 1994; Longley & Richards, 1999): (i) by saving seed from their own harvests; (ii) through other farmers (as loans and gifts, or reciprocal assistance); (iii) by purchasing seed through local grain markets or trade networks; and (iv) through the formal seed sector. Social factors such as wealth, gender, ethnicity and access to land may be significant determinants of seed sources and access to seed (Baniya *et al*., 2000; Louette *et al.*, 1997; McGuire, 2005).

Seed selection is another important aspect of farming and involves a careful and rigorous process to ensure that the farmer has an intact seed lot for the next season. More often, seed is selected after harvest and stored separately but seed may also be selected after storage either before or at planting time. The time, method and criteria for selection may vary with the type of crop or its reproductive system (Almekinders *et al.*, 1994; Bellon & Brush, 1994). In many situations seed selection and seed storage show clear gender differentiation and rural women are often found to be the key players in post-harvest processing and saving seed (Cromwell & Oosterhout, 1999; Song & Jiggins, 2003; Tiruneh, 2001; Walker & Tripp, 1997). On the other hand, cultural factors may exempt women from seed selection and storage. Different methods of selection and storage have been documented and may vary with the type of crop.

Thus the decisions made by farmers with regard to the number and type of varieties to grow, how and where to obtain seed, when to select and how to store seed are influenced by several factors. This, in the end, leads to variations in the way farmers manage diversity.

Diagnostic studies conducted to assess farmers' production constraints in the management and use of sorghum in Ghana underscored the importance of the crop for farmers, for which reason it merits further research attention (Kudadjie *et al.*, 2004). Despite the importance of the sorghum crop there is a dearth of studies aimed at understanding how farmers maintain and manage sorghum diversity in Ghana. There have been, however, a few studies on adoption of sorghum varieties (Dakurah *et al*., 1992; Jatoe, 2000; Jatoe *et al*., 2005; Terborbri *et al*., 2000), marketing and agro-processing (Atokple, 1995; IFAD, 1999; Quaye, 2001), seed storage and seed provision (Lyon & Afikorah-Danquah, 1998; Walker & Tripp, 1997; Wright & Tyler, 1994).

This study is aimed at understanding how farmers manage sorghum diversity and the factors influencing their management of that diversity. The following are the specific objectives of the study:

1. To determine the number and type of varieties maintained by farmers.
2. To identify the selection criteria and concerns of farmers.
3. To determine the seed selection and storage methods employed by farmers.
4. To determine what factors affect farmers' management of sorghum diversity, and how.

Methodology

Selection of study area

The Bawku East district (now a municipality) was purposively selected for this study after a diagnostic study was carried out in two selected villages. In the whole of northern Ghana the district is the lead producer of sorghum in terms of yield and the second highest in terms of cropped area (SRID, 2004). The district shares borders with two neighbouring countries - Togo and Burkina Faso. The Bawku East district is an area of dry savannah, characterized by a short growing season, with periodic drought and poor rainfall, and therefore subject to climatic stress (Dickson & Benneh, 1988). More than two-thirds of the population live in the rural areas. The entire district is also an area of male labour out-migration to southern Ghana, largely attributed to population pressure which has led to land and environmental degradation (Cleveland, 1986, 1991).

Questionnaire design

A questionnaire was designed to gather data on the following:

- Demographic and socio-economic factors;
- Cropping pattern and land allocation to sorghum;
- Farmers' knowledge and use of sorghum varieties;
- Plant traits/characteristics of importance to farmers;
- Factors considered important in the choice of a variety;
- Farmers' seed sources, seed selection, storage and management practices.

Sampling procedure

A stratified multi-stage random sampling procedure was adopted in selecting communities and farmers for the survey. Because of the multi-ethnic nature of the farming communities in the district, and to ensure that each group was adequately represented in the sample, the communities were first stratified by ethnic grouping into Kusasi, Bimoba and a minority group classified as 'mixed', consisting of the Busanga, Mamprusi, Mossi and Yanga tribes. The proportion of the ethnic groups in the district – Kusasi:Bimoba:Mixed (6:3:2) – was determined from village listings by predominant ethnicity, obtained from the District Assembly and Ministry of Food and Agriculture offices. From each stratum, a quota of 20 Kusasi, 11 Bimomba, and 7 mixed farming communities were randomly sampled. From each community, 10–20 households were randomly sampled depending on the number of houses within a community. Ten households were sampled from farming communities with 50 or less houses, 15 households from communities with 75–100 houses and 20 households from communities with over 100 houses. Using information from the District Assembly on the number of houses in a community, randomization was achieved by selecting every fifth house starting from the first house after entering the village.

Data collection

Seven enumerators and two supervisors including the researcher conducted the survey. A two-day training was organized for the team. During this training the objectives of the survey were explained to the enumerators, and questions were discussed and translated into the Kusal language to ensure that the appropriate local words would be used. Three Bimoba-speaking members of the team interviewed the Bimoba, even though most of the respondents who were not Kusasi spoke Kusal quite well. Another day was used to pre-test the questionnaires with 30 farmers in two nearby communities, after which the questionnaires were checked with the enumerators for clarifications and corrections.

The enumerators were organized into two teams – one consisted of three enumerators and a supervisor and the other consisted of four enumerators and another supervisor. The survey was carried out during the month of November 2004 when farmers had just completed all their harvesting. In all, 451 farm households were surveyed. Two hundred and forty-six (246) Kusasi farmers, 121 Bimoba farmers and 84 farmers from the mixed group were interviewed. Each household head was interviewed using a questionnaire (see Appendix 1). Information on cropping pattern, land allocation, knowledge and use of varieties and seed management practices was gathered on a household basis. Information on the importance of plant traits and factors considered important in the choice of sorghum varieties were gathered on an individual farmer basis. Because the respondents were mainly males, one adult female farmer per household was also interviewed at the end, on the importance of plant traits in the choice of varieties.

Data analysis

Descriptive statistics including frequencies, percentages, cross-tabulations and chi-square values were calculated using Statistical Package for Social Sciences (SPSS) v. 12.0. Chi-square on number of respondents was used to establish differences between the social, cultural and economic characteristics of farmers in the number and type of varieties cultivated, land allocated to sorghum, selection criteria and seed management practices. Data were recalculated to percentages for presentation. Depending on the sizes of the contingency tables generated, the phi (φ) coefficient or Cramer's V was also computed to determine the strength of association between the variables measured for the chi-square statistics. For two by two contingency tables, the phi (φ) coefficient was determined, while Cramers' V was determined for bigger contingency tables.

Results and discussion

Demographic and socio-economic factors

Traditionally, farming has formed the main occupation in the Upper East Region. In the Bawku East district, farming was the main occupation for about 98% (n=442) of the farmers interviewed. About 15% (n=78) – of whom 59% were Moslems – had other sources of income apart from farming. These off-farm sources of income were mainly trading (49%) and small-scale industries (41%) such as pottery, agro-processing, blacksmithing, and weaving. The remaining 10% obtained other income through government employment, traditional healing and soothsaying. Generally, more Moslems engaged in trading and artisanal work than did Christians and Traditionalists.

The mean age of respondents (head of household) was 54 years with a mode of 60 years. The sizes of the households surveyed ranged from 2 to 73, with an average size of 13.8. Like the Tallensi, the Kusasi have their domestic units and reproduction units nested within compound structures and formed around a core of agnatically related men. Groups of sons usually continue to live with their fathers even after they are married. Households have several adults living in them and may include closely related married and single men, as well as polygamously married women and the widow of former married male household members (Fortes, 1945). Thus compounds can attain very large sizes. Moreover, these closely related units often farm together. The labour intensity of agriculture in the West African Savannah has caused a high value to be placed on large households because they provide a large work force (Cleveland, 1989; Weil, 1986). In his study on social exclusion in an ecologically comparable area of northern Nigeria, Last (2000) found that in 'deep rural' areas the non-Moslem Hausas (*Magazuwa*) – mainly farmers involved in extensive labour-intensive agriculture – were noted for having large polygynous families, sometimes reaching up to two hundred or more in a single compound, and for living in large isolated farmsteads. These non-Moslems contrasted sharply with the Moslems who usually lived in the villages and towns and had much smaller households. They were primarily traders or craftsmen and did not cultivate large farms as did the *Magazuwa*. Last's observation that trading was associated with conversion to Islam seems to corroborate the findings from this present survey which indicates that more Moslems are engaged in trading and artisanal work, as off-farm sources of income, than are Christians and Traditionalists.

Within the Upper East Region the farm is basically composed of the compound farm and the distant or bush farm. The compound farm is the area cultivated around the residential compound. It is cultivated permanently with animal manure and household compost. The bush farm may be located about 2–6 km away from the homestead (Benneh, 1972). The permanent nature of farming practised has been described as atypical of tropical Africa where shifting and rotational systems feature more prominently, though it is in fact fairly typical for the Sudan Savannah belt in West Africa (Mortimore, 1989). The mean size of compound farms of the households surveyed was 1.3 ha while the mean size of bush farms was 1.2 ha. The average farm size was 2.5 ha. About 54% of the households (n=241) were found to cultivate 2 ha or less. According to IFAD (2006) about 66% of farm families in the region cultivate landholdings of about 2.0 ha or less. Tanzubil (1993) found that in a survey conducted in Bawku, landholdings were generally small and about 80% of farmers surveyed cultivated 2 ha or less of farmland.

Adherents belonged to three main religions; Traditional (40.9%), Islam (36.9) and Christian (22.2%). Out of the six districts in the Upper East region the African traditional religion was found to predominate in five districts including Bawku East district in a study conducted in the Upper East region (IFAD, 1990).

Ninety-two percent of respondents (n=415) used external labour in addition to family labour for their farming activities while the remaining 8% (n=36) depended solely on family labour. External labour was paid for with cash, with food and grain (or seed), or through exchange with labour (reciprocal labour). Labour is the most important farming input. Several studies about farming groups in the West African savannah have shown that the main forms of agricultural labour used are family labour, communal labour and wage labour (O'Laughlin, 1973; Saul, 1983; Whitehead, 1981). Communal labour requires social capital, food (usually prepared from millet or sorghum), copious amounts of local beer prepared from sorghum and sometimes gifts such as kola. Ability to call a communal labour party to work on one's farm therefore requires a sufficient grain stock or money to buy grain. Even though communal labour may be reciprocal, Whitehead (2006) noted that this is mostly not the case because the wealthy always manage to secure more of it. Waged or hired labour (also termed 'by-day' in Bawku) is contracted on a daily basis and paid for with cash.

Crop diversity

The crops grown by the farmers sampled were mainly cereals, vegetables and legumes (Table 1). Over 80% of the farmers grew sorghum, millet, maize and rice. The most widely grown cereal was sorghum (99%), followed by early millet (96%), maize (93%) and rice (85%). More than 65% of farmers grew cowpea, groundnut, bambara groundnut and soybean. A few (12%) grew cotton, which is purely a cash crop. A considerable proportion (44%) grew sweet potato, the only root crop, for cash. Vegetables and legumes were commonly grown during the rainy season while onions were usually grown under irrigation for the market during the dry season.

Farmers grew between two and fourteen different crops (Figure 1). On average, 10.2 (SD=2.5) crops were grown in a season. Farmers who grew between two and seven crops accounted for only 15% of the sample while the majority (84%) grew between 8 and 13 crops. However, it is believed that there is a higher crop diversity than the survey shows. Several leafy vegetables are grown by women for soup ingredients or for the market, but given that most respondents were male these may have been under-reported. In north-western Sierra Leone as many as 62 crops were cultivated by rice farmers in the Kambian district alone (Jusu, 1999).

Table 1. Major crops grown by farmers in Bawku East district (data from 2004 questionnaire).

Major crop	No. of farmers growing	% (n=451)
Sorghum	448	99.3
Early millet	433	96.0
Maize	417	92.5
Groundnut	405	90.0
Cowpea	396	87.8
Late millet	390	86.5
Rice	384	85.1
Okro	362	80.3
Soybean	351	77.8
Bambara groundnut	302	67.0
Onion	280	62.1
Tomato	233	51.7
Sweet potato	202	44.8
Cotton	56	12.4

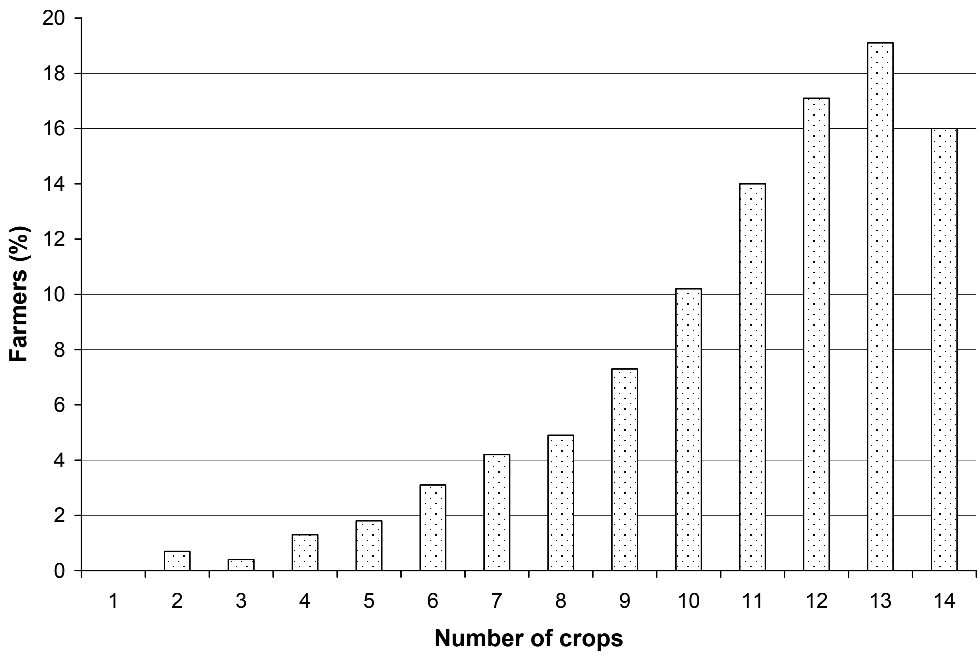

Figure 1. Percentage of farmers growing different numbers of crops in Bawku East district (n=451).

Land allocation to cereal crops

Table 2 shows how farmers ranked the four main cereals in terms of the proportion of land allocated to each crop on a farm. Sorghum was the most widely cultivated cereal crop (n= 448), followed by millet (n=433), maize (n=417) and rice (n=384). Out of the total land allocated to cereals, more farmers (48%) allocated the largest proportion of their land to millet than allocated the largest proportion to sorghum (31%), or maize (28%). Hardly any farmers allocated the largest portion of their cereal land to rice. The cultivation of rice depended on the possession of, or availability for renting, of low-lying land. The situation seems to have changed slightly from what pertained between 1988 and 1990 (IFAD, 1990). During this period the allocation of land (in hectares) by ranking followed a similar pattern to that found in this survey except for maize and rice whose positions assumed reverse order. It could mean that maize is now planted where rice was once planted. The present pattern in allocation still shows millet as the most important cereal, followed by sorghum, and a growing popularity of maize over the years. Even so, sorghum is more widely cultivated than maize throughout the district. A comparison of the four crops on ranking based on area allocated to each cereal makes this clear.

Sorghum diversity at variety level

Nineteen (19) different sorghum varieties, consisting of both early and late-maturing

Table 2. Ranking of cereal crops according to area allocated on the farm by farmers in Bawku East District (data from 2004 questionnaire).

Ranking[1]	Sorghum (n=448)		Early Millet (n=433)		Maize (n=417)		Rice (n=384)	
	Farmers	%	Farmers	%	Farmers	%	Farmers	%
1	140	31.3	206	47.5	116	27.8	4	1.0
2	175	39.0	117	27.0	148	35.5	9	2.3
3	115	25.7	97	22.5	144	34.5	78	20.3
4	18	4.0	13	3.0	9	2.1	293	76.3

[1] 1 = highest; 4 = lowest.

varieties, were found to be grown across the district based on farmers' names for varieties (Figure 2). On average one farmer cultivated 2.5 (SD=1.2) varieties at a time although the highest number of varieties grown was six. In Ethiopia, a centre of diversity for sorghum, McGuire (2002) found as many as 17 different varieties mentioned in one district, and that the two most popular varieties were grown on 88% and 64% of the farms surveyed. In Niger, 33 varieties of pearl millet were found to be grown in 58 villages (Ndjeunga, 2002).

In Bawku East district Belko peleg (late-maturing) and Naga red (early-maturing) were the most popular varieties, planted by 69% and 51% of farmers, respectively. About 39% grew Belko zia (late-maturing) while about one quarter grew Naga white (27%) and Kowerig (26%), both early-maturing. All the other late-maturing varieties, and Salibato, an early type, were grown by less than 7% of the farmers. Webber (1990) noted that the cultivation of Naga red and Naga white by farmers since their introduction in the 1970s was a deliberate strategy for coping with seasonal hunger. They had a critical advantage over the other varieties because they were harvested in the period between the harvest of the early millet and the other late cereals.

Webber (1996) also found that in some areas of Kusasi (Bawku), farmers had ceased entirely to grow traditional long-season (120 days) varieties of sorghum, the perception being that they were no longer adapted to the prevailing rainfall regime. In this study, however, the traditional long-season variety (Belko peleg) was the most widely cultivated variety by farmers across the district. This suggests that for such farmers the rainfall regime may not be a serious problem for its cultivation. On the other hand it may be possible that Webber's study was carried out during a dry period. Frölich and Buah (1991) found that the loose-panicled guinea type (known as the Belko type), with white corneous grain, was the most widely cultivated and adapted of all the races.

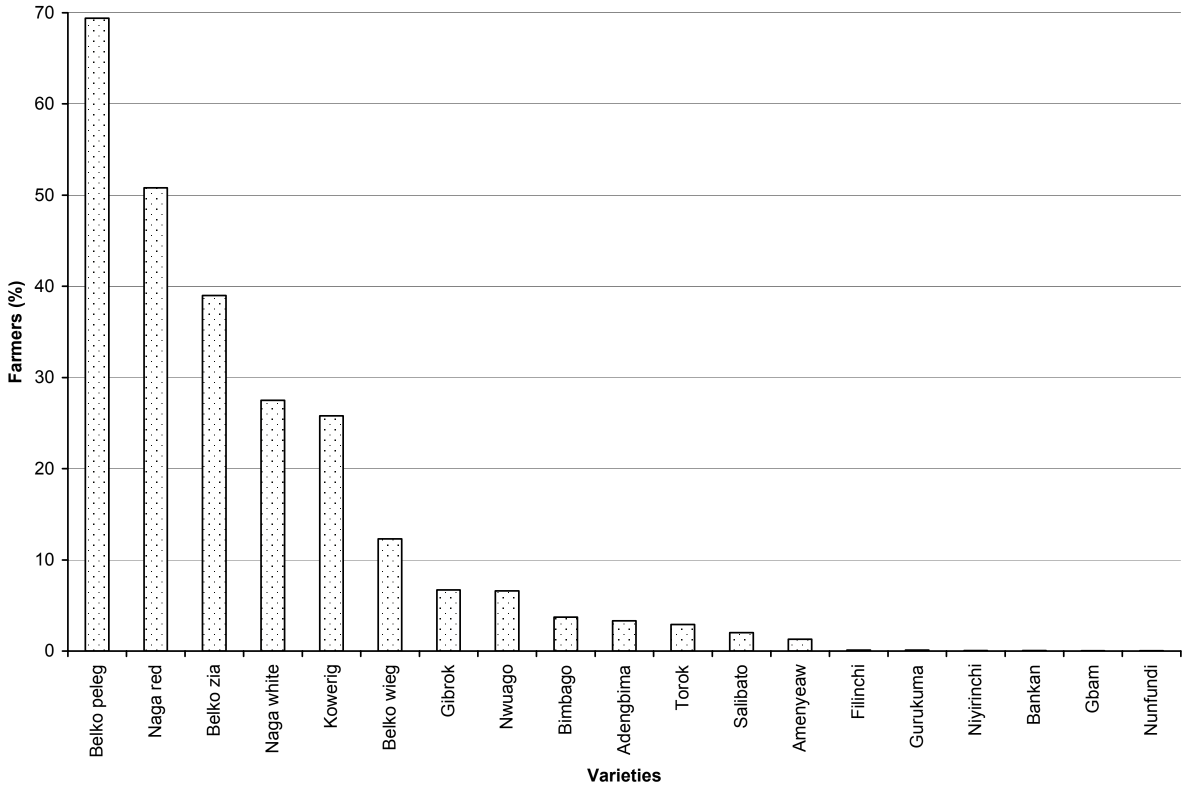

Figure 2. Percentage of farmers growing a particular sorghum variety in Bawku East district (n=448).

Main purpose for sorghum cultivation

Farmers cultivated sorghum for two main purposes: consumption and the market. But the majority cultivated for their consumption only (69%; n = 307) and others for both consumption and the market (25%; n = 113). Very few (6%; n = 28) grew sorghum for the market only. Consumption here refers to food and beer, but it is important to point out that this is for every day use as well as special occasions like celebrations, funerals and festivals and their associated rituals. Table 3 shows how the two most widely cultivated sorghum varieties were consumed. Belko peleg is more widely consumed as food (98%) than Naga red as food (89%). On the other hand Naga red is more widely consumed as beer (62%) than Belko peleg as beer (44%). Belko peleg is said to have grain characteristics and a colour that is better suited for the local food (*tuo zaafi*) and porridge. Its use for beer is more often reserved for the special occasions mentioned above. While Naga red is less suitable for *tuo zaafi*, its red colour and good malting properties makes it a good raw material for beer. Much of the beer sold in the market or drunk every day is prepared from Naga red.

Table 3. Proportion (%) of the two most widely cultivated sorghum varieties consumed as food and beer (data from 2004 questionnaire).

Form of consumption	Most cultivated variety	
	Belko peleg (n=314)	Naga red (n=228)
Food	98.4	89.0
Local beer	43.9	61.8

Maintenance of varieties

The survey showed that about 53% (n=238) of the farmers were no longer cultivating all the sorghum varieties they cultivated 5–10 years ago while the remaining 47% (n=190) maintained the same varieties. Low yields of abandoned varieties (50%; n=110), erratic and unreliable rainfall (19%; n=42), the need for early maturing varieties (12%; n=37), poor soils (9%; n=19) and availability of varieties with better food quality than those originally cultivated (7%; n=16) were the main reasons given for the shift. Other reasons included a need for drought tolerant varieties and a lack of seeds (5%; n=14). This means that farmers look for better varieties to replace those which do not perform well. An important reason given by those who have maintained their varieties was because they were inherited from the previous generation and must be passed on to succeeding generations. Other farmers did not add to their varieties because they had insufficient farmland, or had unsuitable soils.

Planting in mixtures

In this survey, over a third of the farmers (39%; n=173) planted mixtures of varieties on the same piece of land while the remaining 61% (n=275) did not. Frölich & Buah (1991) observed that in Ghana sorghum farmers were generally interested in stable grain yields and consequently cultivated a mixture of two or more cultivars on the same piece of land. In this study farmers had different reasons for planting their sorghum varieties in mixtures (Table 4). More than half (56%) of the farmers were of the opinion that they could avoid total crop failure if they planted in mixtures. Others (19%) planted in mixtures in order to experiment and to compare the performance of the different varieties on the same soil. About 10% planted in mixtures when their varieties matured within the same period while others (6%) claimed that they wanted to encourage competition among the varieties. The reasons why farmers sow in mixtures are not very different from why other farmers in Sierra Leone or The Gambia plant in mixtures. A study on farmer management of rice genetic variability in Sierra Leone revealed that some farmers sowed farm plots to mixtures of rice types to reduce yield losses caused by lodging (Jusu, 1999). Nuijten (2005) found that even though

Table 4. Farmers' reasons for planting different varieties on same piece of land (data from 2004 questionnaire).

Why farmers plant different varieties on same piece of land	Farmers	% (n=173)
Avoidance of crop failure/risk	97	56.0
Trial/experimentation	33	19.1
Same maturity period	17	9.8
Encourage competition	11	6.4
Scarce land	7	4.0
None	2	1.1
Others (tradition, reduce labour)	6	3.5

rice farmers in The Gambia normally cultivated varieties in a pure stand, they planted in mixtures if the maturity dates of different varieties were the same. According to Nuijten, these farmers tested a variety by sowing it in a plot of another variety, either in a small area within the plot or scattered over the entire plot. Richards (1997) also found that farmers match different rice varieties to different soil conditions in Sierra Leone.

Selection concerns

Sorghum selection criteria

Farmers' selection criteria mainly reflected agro-ecological and usage concerns (Table 5). Agro-ecological concerns such as maturity, drought tolerance, resistance to lodging, and adaptation to poor soils were indicated. The use concerns were yield and grain quality. The most frequently indicated criteria for selection were yield (86%) and earliness (67%). This suggests that most farmers considered grain yield an important characteristic, and perhaps more so than any other criterion such as grain quality. Grain quality was mentioned as frequently as adaptation to soils and almost as often as resistance to lodging. Lando & Mak (1994) found that rice farmers cited yield as the most frequent reason to plant a variety, but this trait was also mentioned as frequently as field adaptation and maturity. However, it was found that in no instance did sorghum farmers in Zimbabwe identify yield as an important selection criterion (Van Oosterhout, 1993).

Even though farmers mentioned the above eight criteria, the reasons they provided for growing different varieties (data not shown) indicated that they had other use criteria such as strong stalks (e.g., Naga red, Belko peleg and Belko zia), suitability for brewing *pito* (e.g., Naga red and Belko zia), bird resistance (Naga red), medicine

Table 5. Criteria used by farmers in Bawku East district for selecting sorghum varieties to grow (data from 2004 questionnaire).

Selection criteria	Farmers	% (n=448)
High yielding	384	85.7
Early maturing	301	67.1
Drought tolerance	192	42.8
Good grain quality	105	23.4
Adapted to poor soils	104	23.2
Resistant to lodging	93	20.7
Disease resistance	80	17.8
Big panicles	16	3.6

(Niyirinchi and Nunfundi) and for cultural purposes, e.g., festivals, funerals and ceremonies (Belko types). Therefore, varieties satisfied more than one criterion and therefore served different purposes. While Belko, for example, may not be early or high yielding, it was adapted to local soils, had strong stalks, good *tuo* quality and was important for celebrating the *samanpiid* festival after the harvest. Naga red, on the other hand, was early and high yielding, had poor *tuo* quality and taste, yet had strong stalks and fetched a good price on the market because of its suitability for *pito*.

Importance of selection criteria

The criteria mentioned in Table 5 and other criteria were scored by male farmers and female members of the same household. The results were used to gain an appreciation of the importance of the selection criteria to farmers as a whole, and whether there were differences by gender. Table 6 shows the average ranking based on a three-point scale. Out of a total of 15 characteristics, the average ranking for 13 and 11 characteristics for women and men respectively were between 'very important' and 'somewhat important'. The large number of characteristics ranked as very important or somewhat important indicates that, not only do farmers assess crops on multiple dimensions, but also, it is unlikely that all these characteristics could be satisfied by a single variety. In short, both men and women demand diversity. This is confirmed by the high proportion of farmers cultivating two or more sorghum varieties at a time.

A comparison of men's and women's ranking showed statistically significant differences (using a Wilcoxon signed ranks test) for four traits. Fuel quality (stalks) and ease of threshing, which are also related to women's activities (cooking and threshing), were ranked 'more important' by women than by men. Similarly, adaptation to soil and disease resistance were ranked 'more important' by men, who are more

Table 6. Ranking by importance of selection criterion by male and female members of the same household in Bawku East district (n=448); data from 2004 questionnaire. A Wilcoxon signed ranks test is used to test for statistically significant differences between male and female ratings for different criteria. Ranking is based on a three-point scale (1 = very important, 2 = somewhat important, and 3 = not important).

Characteristic	Average rating		
	Males	Females	P value[1]
Yield	1.05	1.04	ns
Earliness	1.10	1.07	ns
Adapted to poor soil soils	1.20	1.27	0.00
Disease resistance	1.23	1.29	0.04
Striga tolerance	1.22	1.22	ns
Drought tolerance	1.26	1.32	ns
Good storage properties	1.54	1.56	ns
Taste	1.54	1.47	ns
Tuo quality	1.57	1.50	ns
Resistant to lodging	1.86	1.84	ns
Bird resistance	1.95	1.94	ns
Threshability	2.08	1.74	0.00
Malt/*pito* quality	2.20	2.16	ns
Feed quality	2.36	2.40	ns
Fuelwood quality	2.65	1.93	0.00

[1] P value associated with a Wilcoxon signed ranks test for two related samples; ns = not significant.

concerned with in-field activities. This shows that there are gender differences in the demand for sorghum characteristics and that, even within a farming household, men and women have different – and perhaps competing – concerns. Thus, whereas improvements in earliness or yield or taste would be beneficial for both men and women, improvements that come at the cost of ease of threshing, for example, would negatively affect assessments by women more than by men.

Seed management

Seed sources and exchange

Many more farmers tended to use their own seed (89%) or sourced seeds from the market (22%), than from other farmers (2%), or the Ministry of Food and Agriculture

(1%), or Bewda, a non-governmental organization (Table 7). Seeds obtained from other farmers were either in the form of gifts, or through exchange for seed, grain or labour. Seed from the market was paid for in cash. Smale *et al*. (1999b) found that about 90% of maize farmers in Mexico used their own seed. Teshome (2001) also found self-sourced seed and the market respectively to be the first and second most important sorghum seed sources for farmers in Ethiopia. Rohrbach & Tripp (2001) also noted from studies in southern and western Africa that of all the transactions that small-scale farmers undertake to acquire or provide seed, a significant proportion of seed was purchased from other farmers or grain markets. In Ethiopia, although sorghum farmers obtained seed from other farmers more frequently, they were in smaller amounts, while the local market appeared more important for supplying large amounts of seed (McGuire 2005). In this study the market appears to be the most important source of off-farm seed. This supports the claim that local markets are important institutions in local seed systems (Sperling *et al.*, 2004).

In this study the market (60%) and MoFA (32%) were found to be the two most important sources of seeds of new varieties. Other sources were neighbours, relatives and friends (Table 8). The Agricultural Research Institute in the district was a source of new varieties for a few (2%) farmers, mainly because of the proximity of some

Table 7. Farmers' sorghum seed sources in Bawku East District (data from 2004 questionnaire).

Source of seed	%[1] (n=448)
Own seed	89.0
Market	22.0
Other farmers	1.5
MoFA/Bewda	0.8

[1] Figures do not add up to 100 as farmers may use different sources.

Table 8. Sources from which farmers obtain seeds of new varieties in Bawku East District (data from 2004 questionnaire).

Sources of new varieties	%[1] (n=448)
Market	60.3
MoFA	32.0
Neighbours	13.4
Relatives	12.3
Research	2.3

[1] Figures do not add up to 100 as farmers may use different sources.

Table 9. Sorghum seed selection criteria of farmers in Bawku East district (data from 2004 questionnaire).

Criteria	Farmers	% using criterion (n=448)
Panicle size	269	60.0
Grain size	267	59.2
Grain maturity	237	53.0
Clean seed	221	49.0
Healthy grain	220	48.8

Table 10. Sorghum seed selection practices of farmers in Bawku East district (data from 2004 questionnaire).

Practice		% practising (n=448)
Time of selection	At harvest	94.1
	In field	5.6
	During storage/before planting	0.2
Who selects	Men	71.4
	Men and women	22.7
	Women	5.8

communities to the Institute. Even for new varieties, the local market remains an important source of seeds for farmers. A study on farmer seed systems in disaster-affected and stressed communities in seven countries in eastern, central and southern Africa revealed that, for non-hybrids, local seed/grain markets are an important channel for moving new varieties developed by formal research systems (Sperling *et al.*, 2004).

Seed selection

Farmers based their selection on both panicle and grain characteristics. Principally, these were grain size, grain health, maturity and panicle size (Table 9). Two or more of these criteria were used by most farmers (93%; n=420) in selecting seed. The most common seed selection criteria used were panicle size and grain size. Farmers may be selecting for yield when they use these two criteria.

A few farmers (6%) mark plants for selection in the field, but most of the seed selection takes place during harvesting (94%) where the seed is separated from the food grain (Table 10). Hardly any farmer (0.2%) selected seeds just before planting. The usual practice is to cut down all the plants first, then, in the process of cutting off the panicles, those selected for seed are separated from the rest of the harvest. Smale *et al*. (1999b) found that maize farmers in Oaxaca, Mexico, also selected their seed after harvest (based almost exclusively on the characteristics of harvested ears) and pointed out that such an approach is likely to exert direct selection pressure on ear characteristics, but only indirectly on related plant characteristics, since only a minority mark plants for selection. Walker and Tripp (1997) also reported that in Ghana less than 4% of maize and cowpea seed selection occurred in the field. But in Zambia about 18–25% of seed selection for sorghum and cowpea was in the field.

In most cases (71%) seed selection was only done by men, and in other cases both men and women selected seed (23%). In just a few cases (6%) did the women alone select seed. Jusu's study on rice management in Sierra Leone revealed differences between three adjacent chiefdoms with regard to the gender of the persons responsible for seed selection and rogueing. While in one chiefdom selection and rogueing was done entirely by men, in the other two chiefdoms, women and children were involved.

Seed storage

In most cases (76%) men alone stored sorghum seed. However, in some cases (14%) women stored the seed (Table 11). The most common form of storage was to keep the seed in the unthreshed state, stored in the mud silo (63%). Clay pots (13%) were less frequently used. About 63% did not treat their seed before storing while the rest used chemicals, or wood ash. Among the Kusasi, men (who are head of households) are perceived as the provider and keeper of the staples. This role is asserted by their sole control over all staples which are produced and stored in the barn. In Padmanahban's (2002) analysis of gender relations in Bawku West district (Toendema), she suggested that this restricted control by men may be changing. She found that women were also beginning to cultivate and store staples.

Social, cultural and economic factors and farmer management of diversity

Socio-cultural and socio-economic factors provide the context that shape farmers' seed and crop management choices. Social and cultural factors influencing the decisions a farmer makes include his or her traditional practices and way of life, or the identity of the group to which he or she belongs (Jarvis *et al.*, 2000b). Anthropologists recognize the role of culture in determining the varieties farmers choose to grow and decisions about where these are planted.

In this study, the social, cultural and economic factors investigated are ethnicity, religion, farm size, household size, location of communities/villages, and ability to pay for labour.

Table 11. Sorghum seed storage practices of farmers in Bawku East district (data from 2004 questionnaire).

Storage practice		% practising (n=448)
Who stores	Men	75.8
	Women	14.2
	Women and men	9.8
Place of storage	Mud silo	63.3
	Clay pots	13.2
	Room within house	10.7
	Grass barn	5.2
	Open air/trees	4.6
	Sacks	2.4
	Kitchen	0.7
Form of storage	Unthreshed	82.6
	Threshed	17.4
Treatment before storage	None	63.7
	Chemicals	26.9
	Wood ash	8.6
	Neem extract	0.5
	Chemical & wood ash	0.3

Socio-economic and cultural factors influencing the number of sorghum varieties grown

The chi-square test showed a significant difference between religious adherents with regard to the number of sorghum varieties cultivated. Most Traditionalists cultivated more varieties (≥ 3) while most Moslems cultivated fewer (≤ 2) varieties (Table 12). Traditionalists may need to grow more varieties not only to satisfy their food and cash needs but also to meet religious obligations for which beer brewing and drinking is important. For Moslems, however, beer drinking is prohibited. Adherents of the traditional religion must partake in the *samanpiid* festival and perform the required rituals that go along with it. This requires different varieties, some more suitable for food and others for *pito* (local beer), both of which are required in large amounts during such festive occasions. Pallier (1972), cited in Saul (1981), found that in Ouagadougou, half of the grain estimated to be consumed annually on average by a family was

Table 12. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangement indicating the number of sorghum varieties cultivated.

Farmers' socio-economic and cultural characteristics	Categories	Number of sorghum varieties cultivated (n=448) ≤ 2	≥ 3	χ^2 value	V or φ value
Religion	Traditional	38	62	31.85**	0.27
	Moslem	68	32		
	Christian	53	47		
Ethnicity	Kusasi	47	53	28.16**	0.25
	Bimoba	49	51		
	Mixed	80	20		
Location of village	Border	55	45	0.19	0.02
	Inner	53	47		
Farm size (ha)	0.4–1.2	71	29	20.25**	0.21
	1.4–2.0	54	46		
	> 2.2	44	56		
Household size	1–7	61	39	5.34*	0.11
	8–15	54	46		
	> 16	46	54		
Labour	Own labour	63	37	5.7*	0.11
	Paid labour	50	50		

* significant at the 0.05 level;
** significant at the 0.01 level.

transformed into sorghum beer. Beer was also responsible for the large market for sorghum and its subsequent commercialization – and by implication its production – even before the demand for traded food grains arose within farming settlements.

The chi-square test indicated a significant difference between the ethnic groups with regard to the number of varieties cultivated. Many more Kusasi and Bimoba cultivated a larger number of varieties (≥ 3) whereas only a few respondents of mixed ethnicity cultivated a larger number of varieties (Table 12). Sorghum as well as millet is a traditional crop for both the Kusasi and Bimoba. Friis-Hansen (2000) found that the use of sorghum diversity differed between two ethnic farming groups in Tanzania, based on each group's historical subsistence strategies. The Gogo tribe migrated from a sorghum-growing area and cultivated twice as many sorghum landraces as the Bena and Hehe, who migrated from maize dominated areas.

No significant differences were found between respondents living along the borders and respondents living in the inner villages with regard to the number of varieties grown (Table 12). The chi-square test showed a significant difference between the farm sizes of respondents with regard to the number of varieties. A majority of respondents with smaller farm sizes tended to cultivate fewer varieties while more respondents with larger farm sizes tended to cultivate a higher number of varieties (Table 12). Food security may be more critical for farmers with smaller farms than for farmers with larger farms, and since diversity is more linked to yield stability and does not necessarily lead to yield increases, perhaps farmers with small farms might prefer to grow fewer sorghum varieties and devote more land to other staples from which they can obtain a higher output per unit of area.

The significant chi-square value indicates that more respondents with smaller households tended to grow fewer sorghum varieties whereas more respondents with larger households grew more varieties (Table 12). This may be because larger households have more diverse needs which cannot be satisfied by only one variety, or that when labour is abundant farmers prefer to diversify sorghum varieties.

The chi-square test showed a significant difference between respondents who use their own labour and those who pay for labour with regard to the number of sorghum varieties grown (Table 12). More respondents who use their own labour cultivated fewer varieties while more respondents who paid for labour cultivated more varieties. Payment for labour includes paying cash for hired labour, or provision of food and beer for labour parties. Sorghum grain is not only used for food but especially for brewing local beer served to all labour parties called by household heads in turn. Saul's (1983) study on agricultural labour flows in southern central Burkina Faso showed that the grain used in brewing and cooking accounted for the largest portion of the cost of a community labour party. This may explain why respondents who pay for labour need to grow more varieties.

For all the significant chi-squares indicated, a positive association was found as shown by the Cramer's V or phi (φ) coefficient (Table 12).

Socio-economic and cultural factors influencing allocation of land to sorghum

No significant differences were found between religious adherents or ethnic groupings with regard to the proportion of land allocated to sorghum (Table 13). The chi-square test showed significant differences between the two locations of villages in the proportion of land allocated to sorghum. More respondents living along the borders allocated more of their land to sorghum than those living in the inner villages (Table 13). It is possible that farmers living close to the borders cultivate more sorghum in order to take advantage of their proximity to the informal cross-border trade and grain markets (Chalfin, 2001; Saul, 1987). These markets draw together the grain surplus from several towns and villages in southern Burkina Faso and north-west Togo to metropolitan centres in southern Ghana.

There was no significant difference between the farm sizes of respondents with regard to the proportion of land allocated to sorghum (Table 13). The chi-square test indicated significant differences in the proportion of land allocated to sorghum between the household sizes. A larger proportion of smaller households allocated more land to sorghum whereas a smaller proportion of larger households allocated less land to sorghum (Table 13). In the West African savannah region, larger households have more labour and therefore are able to cultivate larger land holdings (Cleveland, 1986;

Table 13. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangement indicating the proportion of cereal land allocated to sorghum.

		Proportion of cereal land allocated to sorghum by rank (n=448)			
Farmers' socio-economic and cultural characteristics	Categories	3rd & 4th (Less)	1st & 2nd (More)	χ^2 value	V or φ
Religion	Traditional	28	72	4.58	0.1
	Moslem	55	45		
	Christian	23	77		
Ethnicity	Kusasi	31	69	5.62	0.11
	Bimoba	22	78		
	Mixed	38	62		
Location of village	Border	20	80	8.59**	0.14
	Inner	34	66		
Farm size (ha)	0.4–1.2	26	74	2.55	0.08
	1.4–2.0	26	74		
	> 2.2	33	64		
Household size	1–7	17	83	15.80***	0.19
	8–15	27	73		
	> 16	41	59		
Labour	Own labour	16	84	14.94***	0.18
	Paid labour	35	65		

** significant at the 0.01 level;

*** significant at the 0.001 level.

Handwerker, 1981; Netting, 1974). Data collected from six communities located about 20 km south-east of Bawku on changes in the wealth status of households between 1975 and 1989 also showed that wealth was positively correlated with household size (Whitehead, 2002, 2006). So, because smaller households are poorer and lack labour, allocating more land to sorghum than other cereals would be less demanding on their labour and other resources.

The chi-square test also showed a significant difference in land allocation to sorghum between respondents who used their own labour and those who paid for labour (Table 13). More respondents who used their own labour allocated a greater portion of their cereal land to sorghum while more farmers who pay for labour allocated a smaller portion of their cereal land to sorghum. Sorghum is a crop of the poor, even though poorer farmers grow fewer varieties. It stands to reason that poorer farmers would allocate more of their land to sorghum than to maize or rice, for example, because these latter crops demand more cash for labour and high cost inputs. But since poorer farmers grow fewer varieties overall, off-farm and inter-communal means to protect their access to varieties of choice may be important for poverty alleviation.

A positive but weak association was indicated by the Cramer's V or phi (φ) coefficient for all the significant associations indicated by the chi-square test (Table 13).

Socio-economic and cultural factors influencing the type of varieties grown

The two varieties under discussion are Belko peleg and Naga red. From this survey, Belko peleg was the most widely cultivated local variety while the Naga red variety was the most widely cultivated improved variety in the district.

The chi-square test indicated significant differences between the religious adherents with regard to the cultivation of Belko peleg (Table 14). There were more Moslems and Christians who did not cultivate Belko peleg and fewer Traditionalists who did not cultivate Belko peleg. The chi-square table indicates that 92% of the Kusasi while less than 70% of the Bimoba and Mixed ethnic group cultivated Belko peleg – a significant difference (Table 14). Belko peleg is used for sacrifices to the ancestors, for libations and for brewing beer for the celebration of the *Samanpiid* festival by tradition-oriented Kusasi (Kudadjie *et al.*, 2004). This explains why more Traditionalists than Moslems cultivated the variety. The cultural value placed on this variety by the Kusasis has encouraged its maintenance over the years. A parallel is found among the Mossi farming communities in neighbouring Burkina Faso who use their red sorghum types (*Karaga*) for brewing beer for their traditional religious festival (Saul, 1981).

The chi-square test showed significant differences between respondents living along the borders and those living in the inner villages with regard to the cultivation of Belko peleg. Most of the respondents living in the inner villages cultivated Belko peleg whereas fewer farmers living in the border villages cultivated Belko peleg (Table 14). This may be explained by the relation between ethnicity and location of villages. Many more Kusasi live in the inner villages than in the border villages. Most of the people living in the villages bordering north-west Togo and the north-east of Ghana are Bimoba or belong to other ethnic groups, while the majority of those living in the inner villages are Kusasi.

The chi-square test showed significant differences between farm sizes as to the cultivation of Belko peleg. Fewer farmers with small landholdings cultivated Belko while more farmers with larger land holdings cultivated the variety (Table 14). Because Belko peleg is late maturing, farmers with less land may prefer to grow less of it and grow other crops or varieties which mature early in order to cultivate a second crop before the end of the growing season. It is common to find farmers cultivating sweet potatoes after harvesting the early millet in Bawku.

Table 14. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangement indicating whether or not they cultivate Belko peleg.

Farmers' socio-economic and cultural characteristics	Categories	Belko peleg cultivated (n=448)			
		No	Yes	χ^2 value	V or φ
Religion	Traditional	12	88	12.28**	0.17
	Islam	26	74		
	Christian	20	80		
Ethnicity	Kusasi	8	92	47.78**	0.33
	Bimoba	31	69		
	Mixed	37	63		
Location of village	Border	32	68	19.34**	0.21
	Inner	14	86		
Farm size (ha)	0.4–1.2	30	70	13.75**	0.18
	1.4–2.0	21	79		
	> 2.2	13	87		
Household size	1–7	20	80	0.87	0.04
	8–15	21	79		
	> 16	17	83		
Labour	Own labour	22	78	0.91	0.05
	Paid labour	18	82		

** significant at the 0.01 level.

The Cramer's V or Phi (φ) coefficient indicated positive association for all significant associations indicated by the chi-square test. The chi-square test did not show any significant differences in household size or ability to pay for labour with regard to the cultivation of Belko peleg (Table 14). This seems to underline Belko peleg's specific association with traditional religious practice rather than with beer production associated with the involvement of large households in exchange labour. On the other hand the chi-square test indicated no significant differences between religious adherents as to the cultivation of Naga red, another variety associated with brewing (Table 15). What the chi-square test brings out, however, is significant differences between ethnic groups with regard to the cultivation of Naga red (Table 15). More Bimoba and respondents of mixed ethnicity cultivated Naga red than did Kusasi. The significant chi-square values also confirmed a tendency for cultivation of Naga red to be more likely among respondents living along the borders than respondents living in the inner villages. Naga red has no cultural or religious significance for the

Table 15. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangement indicating whether or not they cultivate Naga red.

Farmers' socio-economic and cultural characteristics	Categories	Naga red cultivated (n=448) No	Yes	χ^2 value	V or φ
Religion	Traditional	47	53	0.92	0.04
	Islam	52	48		
	Christian	49	51		
Ethnicity	Kusasi	59	41	21.68**	0.22
	Bimoba	35	65		
	Mixed	39	61		
Location of village	Border	30	70	25.19**	0.24
	Inner	57	43		
Farm size (ha)	0.4–1.2	57	43		
	1.4–2.0	49	51	1.74	0.06
	> 2.2	53	47		
Household size	1–7	51	49	3.6	0.09
	8–15	46	54		
	> 16	49	51		
Labour	Own labour	47	53	0.24	–0.02
	Paid labour	50	50		

** significant at the 0.01 level.

Kusasi. Moreover, it is not preferred for food. Therefore for the Kusasi the only driving factor influencing the cultivation of Naga red may be the market, whereas the Mossi, for example, who form part of the mixed group, consider Naga red types to be among their traditional varieties. About four varieties of red sorghum are grown extensively in the border zone farming communities in southern Burkina Faso. During the diagnostic study (Chapter 2) several farmers claimed that Naga red was introduced from Mossi communities living in Burkina Faso. Furthermore, the proximity of the Bimoba (many of whom reside in border villages), to neighbouring villages in southern Burkina Faso may be a strong influence on their cultivation practices and their higher propensity for growing Naga red.

The chi-square test did not show any significant differences in farm size, household size or ability to pay for labour with regard to the cultivation of Naga red (Table 15).

Socio-economic and cultural factors influencing selection concerns

The two most important selection criteria for sorghum used by farmers in this study were found to be yield and earliness. These two criteria are discussed below.

The chi-square test did not indicate any significant differences in religion of respondents with regard to the choice of yield as a criterion for selecting sorghum varieties (Table 16). Significant differences were found between ethnic groups with regard to the choice of yield as a selection criterion. More Kusasi and Bimoba indicated yield as a selection criterion, while very few respondents of mixed ethnicity gave such indications (Table 16).

The significant chi-square value revealed more respondents with smaller farm sizes indicating yield as a selection criterion and fewer respondents with larger farm sizes indicating yield as a criterion (Table 16). With regard to the choice of yield as a selection criterion there were significant differences between respondents who paid for labour and those who did not. Even though yield is important for all respondents, more respondents who pay for labour indicated yield as a criterion and fewer respondents not paying for labour provided such an indication. Farmers who pay cash for labour would prefer to cultivate high-yielding varieties because they want higher returns to paid labour. It has been found elsewhere (in Asia, for example) that pressure on land and labour increases the importance of yield as a selection criterion for farmers (Lipton & Longhurst, 1989).

The chi-square test showed no significant differences between household sizes of respondents with regard to the choice of yield as a criterion for selecting sorghum varieties. The Cramer's V or phi (φ) coefficients showed weak positive values for all the significant associations indicated by the chi-square test.

Table 16. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangement mentioning high yield as a selection criterion.

Farmers' socio-economic and cultural characteristics	Categories	High yield as a selection criterion (n=448)			
		Yes	No	χ^2 value	V or φ
Religion	Traditional	86	14	0.66	0.04
	Moslem	86	14		
	Christian	83	17		
Ethnicity	Kusasi	86	14	7.18*	0.13
	Bimoba	79	21		
	Mixed	93	7		
Location of village	Border	82	18	1.97	–0.06
	Inner	87	13		
Farm size (ha)	0.4–1.2	87	13	6.7*	0.12
	1.4–2.0	91	9		
	> 2.2	81	19		
Household size	1–7	86	14	0.22	0.02
	8–15	86	14		
	> 16	84	16		
Labour	Own labour	79	21	4.85*	–0.10
	Paid labour	88	13		

* significant at the 0.05 level.

No significant differences were found between religious adherents, ethnic groups, location, payment for labour or farm sizes of respondents with regard to the choice of earliness as a criterion for selecting sorghum varieties (Table 17). Generally, earliness is an important criterion for almost all farmers.

The chi-square test indicated significant differences between household sizes of respondents with regard to the choice of earliness as a selection criterion. The phi coefficient indicated a very weak but positive association between earliness as a criterion and household size (Table 17). It was slightly more likely for the largest and smallest households to indicate earliness as a selection criterion, and for fewer medium-sized (8–15 persons) households to indicate earliness as a criterion (Table 17). In Bawku – as well as other parts of the Upper East region – the long dry season and the first two months of the rainy season are often characterized by hunger in some households. The food situation is likely to be more critical in smaller households,

Table 17. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangement mentioning earliness as a selection criterion.

Farmers' socio-economic and cultural characteristics	Categories	Earliness as a selection criterion (n=448)			
		Yes	No	$\chi2$ value	V or φ
Religion	Traditional	72	28	3.46	0.08
	Moslem	66	34		
	Christian	62	38		
Ethnicity	Kusasi	67	33	0.84	0.04
	Bimoba	65	35		
	Mixed	69	31		
Location of village	Border	69	31	0.07	0.04
	Inner	67	33		
Farm size (ha)	0.4–1.2	67	33	1.5	0.05
	1.4–2.0	67	33		
	> 2.2	71	29		
Household size	1–7	67	33	5.3(*)	0.11
	8–15	64	36		
	> 16	67	33		
Labour	Own labour	63	37	1.47	–0.05
	Paid labour	69	31		

(*) significant at the 0.10 level.

because small households represent poverty in people, and their productivity is probably lower than in larger households. On the other hand, even though larger households may not be considered poor, the need to feed many people at a given time may explain the demand for some earlier maturing varieties in large households.

Socio-economic, cultural factors influencing seed selection and storage

No significant differences were found between religious adherence, location, payment for labour, farm sizes or household sizes of respondents with regard to the gender of the person who selected seed (Table 18). The chi-square test indicated a significant difference between ethnic groupings and the gender of the person who selected seed. The V coefficient indicated a positive association between seed selection and ethnicity.

More Kusasi and Bimoba indicated that men alone, or men with women, selected seed, whereas more respondents from the mixed group indicated that women alone

Table 18. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangements indicating who selects sorghum seed.

Farmers' socio-economic and cultural characteristics	Categories	Who selects seed (n=448) Women	Men	M & W	χ^2 value	V or φ
Religion	Traditional	9	67	25	4.95	0.11
	Moslem	6	70	24		
	Christian	4	77	18		
Ethnicity	Kusasi	4	71	25	15.94**	0.19
	Bimoba	6	68	26		
	Mixed	12	78	10		
Location of village	Border	8	70	22	1.14	0.05
	Inner	5	72	23		
Farm size (ha)	0.4–1.2	9	77	14	8.53	0.14
	1.4–2.0	6	67	28		
	> 2.2	4	72	24		
Household size	1–7	7	69	24	2.6	0.08
	8–15	7	70	23		
	> 16	4	77	19		
Labour	Own labour	10	69	21	5.3	0.11
	Paid labour	4	72	24		

** significant at the 0.01 level.

selected seed (Table18). This difference is explained by the fact that among the Kusasi, seed selection and storage is more often considered the preserve of men (Chapter 6).

The chi-square test showed significant differences between religious adherents with regard to the gender of the person who stored seed. The V coefficient indicated a weak but positive association between seed storage and religion. More Moslems indicated that women were responsible for storing seed while fewer Traditionalists or Christians indicated that women stored seed (Table 19). If trade is more associated with conversion to Islam than with traditional religion (as found by Last (2000) from his study in northern Nigeria), and as suggested by the greater involvement of Moslems in trading as an off-farm activity (this survey), then probably Moslem men are at home less often than men of other religions. This may explain why more women would take over their husbands' responsibilities (e.g., seed storage) among Moslem households.

Table 19. Percentage of respondents in the categories of religion, ethnicity, village location, farm size, household size and labour arrangements indicating who stores sorghum seed.

Farmers' socio-economic and cultural characteristics	Categories	Who stores seed (n=448) Women	Men	M & W	χ^2 value	V or φ
Religion	Traditional	10	81	9	10.25**	0.15
	Moslem	19	74	7		
	Christian	14	71	15		
Ethnicity	Kusasi	14	79	7	8.98	0.14
	Bimoba	15	69	16		
	Mixed	13	78	8		
Location of village	Border	16	71	13	2.85	0.08
	Inner	14	78	8		
Farm size (ha)	0.4–1.2	12	80	8	1.76	0.07
	1.4–2.0	14	74	12		
	> 2.2	16	75	9		
Household size	1–7	15	69	16	5.28	0.10
	8–15	15	77	7		
	> 16	12	77	11		
Labour	Own labour	14	75	11	0.21	0.02
	Paid labour	14	76	10		

** significant at the 0.01 level.

Final remarks

Based on this survey sorghum is the most widely cultivated cereal in the Bawku East district. Of the total land allocated to the four main cereals in the area sorghum ranks second in place to millet. There appears to be a high level of diversity at the district level especially considering that Ghana is not a centre of diversity. This observation about diversity, however, is purely based on named varieties as the study did not include measurement of morpho-phenological descriptors or molecular data. Thus further work is required on morphological and molecular characterization in order to establish the true extent of diversity of the varieties managed by farmers.

Farmers' selection criteria are largely related to agro-ecological and use concerns. Both men and women value diversity, but even within the same household important gender differences exist in the demand for sorghum characteristics. These differences are related to the roles they perform. The large number of characteristics rated as very important or somewhat important is an indication that farmers require a range of sorghum types. This has implications for breeding and should motivate breeders to provide farmers with access to diversity.

The results from the survey support the view that local markets play a significant role in farmers' access to seed, whether local or improved. This suggests the need to pay greater attention to the market when considering farmers' seed sources.

Seed selection and storage are mainly male dominated tasks but women are not entirely excluded from them. Ethnicity and religion are explanatory factors for this level of exclusion/involvement in seed related activities.

Contrary to the view that farmers in Bawku had ceased to grow traditional long-season varieties of sorghum, backed by provisional findings from the diagnostic study that appeared to indicate that sorghum was losing its importance, it was found (from the survey reported in this chapter) that a majority of farmers still maintain long-season varieties. In particular, Belko peleg was the most widely cultivated variety throughout the district. This variety is particularly associated with Kusasi traditional religion, and the importance of sampling across an entire community, and not only in a few accessible villages, is emphasized. The strongest factors influencing farmer use and management of sorghum diversity are ethnicity, religion, farm size and labour considerations. Of these four factors ethnicity and religion play a large and important role in maintaining the local varieties of sorghum cultivated in the district. It can be argued that so long as Kusasi adherence to local religious rituals remains high sorghum will remain an integral part of daily life in these farming communities.

Given that labour is an essential input for farming, and that ability to pay for labour is ultimately dependent on availability of sorghum grain or money, one could also argue that sorghum grain and/or money is essential for farming. Both are currencies that can be converted, and both can be used as payment for farm labour.

The general argument from the results of this survey is that there seems to be a grain farming complex in Bawku supported and influenced by a matrix of beer brewing, labour provision and exchange, and traditional religious festivals, through which the demand for and maintenance of sorghum varieties continues to be sustained. This fact, though hidden from the initial diagnostic study in two villages, has become clear through a well-randomized quantitative survey. Even so, relevant anthropological background information was needed in order to make sense of the data. To put it in another way, the anthropological information made it possible to spot the sociological importance of statistically significant associations in the data. This clearly underscores the value of combining quantitative and qualitative approaches to making sense of complex data sets using the convergence of sciences approach.

CHAPTER 4

Sorghum genetic diversity in north-east Ghana

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important staple cereal cultivated in Ghana. It occupies about 52% of the total area of 567,945 ha of cereals in northern Ghana (SRID, 2001). Farmers in northern Ghana cultivate several varieties (Anon., 1997; Terborbri *et al.*, 2000). In north-east Ghana, farmers cultivate both local landraces and improved or introduced varieties of sorghum. The diversity in growth cycle, plant architecture, and suitability of grains and stover for use by humans and animals determine the value placed on individual varieties and the extent of cultivation (Kudadjie *et al.*, 2004). Farmers place a high premium on their landraces especially because of the specific and distinct roles these landraces play in socio-cultural, economic and religious aspects of their lives. Landraces are valuable sources of desirable genes for modern plant breeding programmes (Harlan, 1992; Prasado *et al.*, 1989). But some of the landraces are gradually being neglected. Such varieties which are no longer being cultivated are either late maturing, low yielding or no longer adapted to the changing climatic and environmental conditions. This might eventually lead to loss of diversity within the crop, especially where such varieties play a role of reduced significance in the lives of farmers.

Bishaw (2004) outlined four main ways in which genetic diversity may be useful. These are: (1) in broadening the base of our food crops through domesticating wild species into cultivated crops; (2) in providing variation for selection among plant populations for crop improvement by plant breeders or farmers (3) in formulating and developing strategies for *in-situ* and *ex-situ* germplasm conservation and maintenance; and (4) by providing farmers and producers with a wide range of choices to select varieties adapted to specific environmental niches. Availability of a wide range of diverse varieties to the farmers is the focus of this study. Genetic diversity is a vital resource for crop improvement. Where there is insufficient or no empirical information about the genetic diversity of a crop, its efficient conservation and/or utilization becomes very limited. Genetic diversity provides security, helps small farmers to maximize production in variable environments, and provides communities with a range of products for multiple uses (Cooper *et al.*, 1992).

Efforts to improve sorghum in Ghana have suffered setbacks and constraints. Some of the factors which posed challenges to sorghum breeding in the country were poor collection and documentation of local cultivars, rapid turnover of scientists over the years, and lack of suitable improved introductions (Anon., 1994b, 1997; Shipprack & Mercer-Quarshie, 1984). For the past six decades only seven sorghum varieties have been released or recommended for release in the country (Manful *et al.*, 2001). Poor taste and food quality, poor storage and the requirement for fertile soils for the improved varieties are among some of the reasons for poor patronage by farmers (Kudadjie *et al.*, 2004; Terborbri *et al.*, 2000). Studies showed that farmers considered their own varieties better than improved varieties with regard to taste, suitability for their local food and resistance to drought, pests and diseases (Jatoe, 2000; Terborbri *et al.*, 2000).

Presently there is an incomplete national core collection of sorghum germplasm and insufficient information on the genetic variability of sorghum varieties cultivated by farmers in Ghana. Studying the genetic variation of sorghum germplasm collections in Ghana thus attracts a special interest because conservation of varieties and their use in improvement programmes require an understanding of the variation present in the gene pool.

Knowledge on the extent of genetic variation of a crop is essential for the utilization of germplasm collections (Lee, 1995) and for establishing a core collection of germplasm for effective germplasm management (Brown *et al*., 1996; Van Hintum, 1994). Sorghum accessions collected in Ghana have undergone classical agro-morphological characterization but there is a need to combine this with molecular methods to ensure a more complete and informative characterization (Atokple, 2003). Results of molecular studies are considered complementary to agronomic and morphological characterization (Karp *et al*., 1997). DNA-based techniques have been used in genetic diversity studies in sorghum and other crops (Aldrich & Doebley, 1992; Agrama & Tuinstra, 2003; Ayana *et al*., 2000; De Oliviera *et al*., 1996). Agrama & Tuinstra (2003) found that SSR markers provide a more powerful assay for discriminating genetic diversity among sorghum accessions than Random Amplified Polymorphic DNA (RAPD) markers. SSRs display high levels of polymorphism (Brown *et al.*, 1996); they can also be amplified by the polymerase chain reaction (PCR) and efficiently detect DNA polymorphism (Pejic *et al*., 1998).

In this study we aim to assess the genetic diversity of sorghum germplasm cultivated in the Bawku East District, to generate information on the variation existing in the sorghum germplasm in the country.

Bawku East district is one of six districts in the Upper East region of the country and is bordered by Togo and Burkina Faso in the east and north, and by Bawku West and East Mamprusi districts in the west and south respectively. Rural markets close to the international borders serve as points for exchanging grain with traders from the other two countries. It was expected, therefore, that unique and useful genetic material, unavailable in other sorghum growing areas of Ghana, might be found.

The specific objectives were as follows:

- to characterize the germplasm used by farmers by investigating agronomic and phenotypic traits;
- to assess the genetic variation among and within varieties using DNA techniques.

Methodology

Morphological characterization

Collection of plant materials

Fifty-six sorghum accessions were obtained from farmers in the Bawku East district, after the harvest in January 2003. To ensure a representative collection, the district was divided into five zones. Zone 1 covered the region bordering Burkina Faso, Zone 2 covered the region bordering the Bawku West district, Zone 3 covered the region bordering Togo, Zone 4 covered the region bordering the East Mamprusi district and Zone 5 was the central portion of Bawku East district. Three villages were randomly selected from each of the five zones. In each village a panicle of each sorghum type grown by the farmers was collected after a group discussion with farmers on types grown. The collection list, common or local name used by the farmers, and ethnicity of each farmer providing a sample are shown in Table 1. Using common names provided it appears that the entire collection covers a greater range of diversity than currently found in any single village. For example, and excepting extinct varieties, only 60% of the total collection was found in two villages sampled in the diagnostic study.

Field experiment

The accessions were planted during the 2003/2004 and 2004/2005 crop seasons to assess their agronomic and morphological diversity. Each accession was grown in a single row plot of 5 m long with 0.75 m between rows and 0.20 m plant distance within rows. There were two replications in a randomized complete block design. In the 2003/2004 season the sorghum seeds were planted at Manga, an out-station of the Savannah Agricultural Research Institute, located about 6 km south of Bawku. The soils at Manga are developed over granites and are red and brown sandy loams associated with hornblende granites. A pre-emergence herbicide (Lasso-atrazine) was sprayed on the plot at a rate of 3.5 L ha^{-1}. Two to three seeds were sown on 26th June 2003 after ploughing and the plant stand was later thinned to one plant per hill. Fertilizer (40:30:30 NPK) was applied at the rate of 300 kg ha^{-1}.

Table 1. List of sorghum accessions, village and zone of collection, and ethnic identity of the farmer from whom the sample was obtained.

Accession number	Local/common name	Village	Zone	Ethnic group of farmer cultivating
* BED1	Belko Nwuago	Woriyanga	5	Kusasi
* BED3	Belko zia**	Woriyanga	5	Kusasi
* BED4	Bumbago	Garu	4	Kusasi
* BED5	Naga white	Garu	4	Kusasi
* BED6	Naga	Garu	4	Kusasi
* BED7	Naga	Zulugu	2	Kusasi
* BED8	Naga	Bugri	4	Busanga
* BED9	Jerry Bumbalug	Ninkogo	1	Bimoba
* BED10	Belko peleg***	Kpatia	5	Kusasi
* BED12	Kapaala	Woriyanga	5	Kusasi
* BED13	Naga white	Kpatia	5	Kusasi
* BED14	Jerry	Denugu	5	Bimoba
* BED15	Belko peleg	Woriyanga	5	Bimoba
* BED16	Naga white	Bugri	4	Kusasi
* BED18	Naga	Kpatia	5	Kusasi
* BED 19	Belko peleg	Garu	4	Kusasi
* BED20	Naga zula	Woriyanga	5	Kusasi
* BED21	Nwuago	Garu	4	Busanga
* BED22	Naga	Binduri	2	Kusasi
BED23	Belko peleg	Bugri	4	Kusasi
* BED24	Nwuago	Nyorugo	2	Kusasi
* BED25	Belko	Nyorugo	2	Kusasi
* BED26	Belko	Zambala	4	Kusasi
* BED27	Belko	Bugri	4	Kusasi
* BED28	Gibrok	Zulugu	2	Kusasi
* BED29	Adengbima	Zambala	4	Busanga
BED31	Belko zia	Kpatia	5	Kusasi
BED32	Niyirinchi	Nyorugu	2	Moshi
* BED33	Torok	Garu	4	Kusasi
* BED34	Belko zia	Bugri	4	Kusasi

* used for molecular characterization;
** local colour category for white or cream;
*** local colour category for red or brown.

Table 1. Continued. List of sorghum accessions with their names, village and zone of collection, and ethnic identity of the farmer from which the sample was obtained.

Accession number	Local/common name	Village	Zone	Ethnic group of farmer cultivating
BED35	Amanyeaw	Binduri	2	Mamprusi
BED37	Kara-zeok	Binduri	2	Moshi
* BED39	Belko zia	Missiga	1	Kusasi
* BED40	Belko zia	Garu	4	Busanga
* BED41	Naga	Gozesi	1	Kusasi
BED42	Amanyeaw	Gozesi	1	Kusasi
* BED45	Naga	Zulugu	2	Kusasi
* BED46	Amanyeaw	Woriyanga	5	Busanga
BED47	Belko zia	Denugu	5	Bimoba
* BED48	Tallas	Denugu	5	Bimoba
*BED49	Songo-mui	Denugu	5	Bimoba
* BED50	Torok	Zulugu	2	Kusasi
BED52	Akumlimnua	Gozesi	1	Kusasi
BED53	Belko	Zulugu	2	Kusasi
BED54	Belko peleg	Tesnatinga	3	Kusasi
* BED55	Yayua	Mandaago	3	Busanga
BED58	Gudure	Mandaago	3	Busanga
* BED59	Zula	Ninkogo	1	Busanga
* BED60	Eyadema	Tesnatinga	3	Kusasi
* BED61	Kapaala	Mandaago	3	Busanga
* BED63	Gudire	Ninkogo	1	Busanga
* BED64	Beninga/Belko	Denugu	5	Bimoba
BED65	Zia	Mandaago	3	Busanga
* BED66	Nwuago	Mandaago	3	Busanga
* BED67	Widki	Ninkogo	1	Kusasi
* BED68	Belko peleg	Tesnatinga	3	Kusasi

* used for molecular characterization.

In the 2004/2005 season, the seeds were planted on 5th June at Pusiga, located about 18 km north-east of Bawku and about 25 km from Manga. The soils at Pusiga are developed over biotite granites and are grey sandy loams.

Data collection
Weather data were obtained from the meteorological department at the out-station of the Savannah Agricultural Research Institute in Manga.

The agronomic and morphological characteristics were recorded on a plot basis either in the field or after harvest. The agronomic characteristics measured were days to 50% flowering (DFF), plant height, panicle length, panicle width, threshed grain weight and hundred grain weight. Visual examination and scoring of morphological characteristics were done using the International Board for Plant Genetic Resource (IBPGR) and ICRISAT Descriptor list for sorghum (IBPGR/ICRISAT, 1993). A colour chart was used for determining the glume, grain and plant colours.

Agronomic and morphological characteristics were assessed as follows:

Agronomic characteristics (based on 10 randomly selected plants per plot)
- Days to 50% flowering (days): from emergence to when 50% of plants in the plot flowered.
- Plant height (cm): distance from ground level to tip of inflorescence of main stalk taken at 50% flowering.
- Panicle length (cm): from base of panicle to its tip.
- Panicle width (cm): in natural position at the widest part.
- Threshed grain weight (g): weight of grains harvested at maturity after threshing panicle and winnowing.
- Hundred grain weight (g): weight of 100 grains after harvest.

Hundred grain weight and panicle width were measured only in the 2003/2004 season.

Morphological/phenotypic characteristics (based on 10 randomly selected plants per plot)
- Plant colour: at harvest; scored as pigmented (1) or tan (2).
- Panicle compactness and shape; scored from 1 to 12 as very lax (1), very loose drooping (3), loose drooping (5), semi-loose erect (7), compact elliptic (9), broom corn (12).
- Panicle exsertion; measured on scale of 1 to 4 as slightly exserted (1), exserted (2), well exserted (3), peduncle recurved (4).
- Glume colour: at maturity scored as: white (1), sienna (2), mahogany (3), red (4), purple (5), black (6), grey (7).
- Grain covering: amount of grain covered by glumes; measured on a scale of 1 to 9 as: 25% grain covered (1), 50% grain covered (3), 75% grain covered (5), grain fully covered (7), and glumes longer than grain (9).

- Awning: at maturity; measured as present (1) or absent (0).
- Shattering: measured on a scale of 1 to 9 from very low to very high.
- Grain colour: at maturity scored as white (1), yellow (2), red (3), brown (4), buff (5).
- Grain lustre: at maturity; scored as present (1) or absent (0).
- Endosperm colour: at maturity scored as: white (1), yellow (2).
- Endosperm texture: measured on a scale of 1 to 9: completely corneous (1), mostly corneous (3), intermediate (5), mostly starchy (7), completely starchy (9).

Data analysis

Descriptive statistics including ranges, means and standard deviations of the means and coefficients of variation for each of the agronomic traits were obtained on the basis of averages over the two seasons. Analysis of variance was used to determine the contribution of genotype, and season/environment to total variation for each agronomic characteristic, using the Genstat 5 software package (release 4.2). Frequency distributions for the morphological characteristics were obtained using the SPSS 9.0 software package.

Molecular characterization (DNA analysis)

Plant material

Molecular analysis was conducted on forty-two of the samples collected (Table 1) and genetic variation within four late-maturing accessions (BED4, BED7, BED19 and BED68) was assessed. Analysis of the variation within an accession (represented by a single panicle) was necessary to confirm the observations made on farmers' fields during the diagnostic study (Chapter 2). Intra-varietal variation (variation within a panicle) was observed within farmers' fields containing late-maturing sorghum types.

Plant materials used for assessing the genetic variation within the four accessions were obtained after growing plants from seeds to maturity and harvesting the seeds from one plant selected at random from one of each of four accessions.

DNA isolation

Seeds were sown in pots and seedlings harvested seven days after emergence. A seedling of each accession weighing between 0.1 and 0.2 g was ground to powder using a mortar and pestle under liquid nitrogen. DNA was extracted using the Qiagen spin column extraction method (Dneasy Plant Mini kit, Qiagen, Leusden, The Netherlands).

The quality of DNA was assessed by electrophoresis in 0.8% agarose gels and the concentration was estimated by using a spectrophotometer. Extracted DNA samples were stored at –20 °C.

PCR analysis
Six SSR markers described by Brown *et al.* (1996) and nine described by Taramino *et al.* (1997) were used for genotyping assays (Table 6). PCR reactions were performed in a Thermohybaid thermocycler in a final volume of 25 μl containing 10 ng of sorghum genomic DNA, 5 pmol of each primer and a PCR bead containing 1.5 units of Taq polymerase, 10 mM Tris-HCL, (pH 9.0), 50 mM KCL, 1.5 mM $MgCl_2$, 200 uM of each dNTP and stabilizers, including BSA.

PCR cycling conditions were: 2 min initial denaturation at 95 °C, 30 cycles of (1 min at 95 °C denaturation, 1 min at 60 °C (Tm), 1 min elongation at 72 °C) followed by a final elongation at 72 °C for 1 min for 1 cycle. Amplification products were resolved by gel electrophoresis in 3% metaphor agarose gels run in 1 × TAE buffer, pH 8 for 4 h at 45 volt. The gel was stained with ethidium bromide (10 mg ml^{-1}) and the DNA fragments (bands) were visualized using a UV trans-illumination device and photographed using a Polaroid camera.

Data analysis
A band was scored as present (1) or absent (0) for each of the genotypes. Cluster analysis was based on similarity matrices obtained with the unweighted pair-group method (UPGMA) using the arithmetic average to estimate the phenogram. All the data analyses were performed with the software package NTSYS-pc (Rolf, 2000).

Results and discussion

Rainfall and diversity in agronomic and morphological traits
The total rainfall recorded during the cropping season for 2003/2004 and 2004/2005 was 1030 and 587 mm respectively (Table 2). The large difference between the two seasons is mainly because of differences in rainfall figures recorded from August to October. In the second season the rains ended much earlier than did the rains in the first season. This difference in the 2004/2005 growing season did not appear to greatly affect the performance of the crops. This is because the demand for water is less during grain filling and ripening than at booting and flowering. In the 2003/2004 season, however, a high incidence of spittle bugs was observed during periods of drought in June and July. Dry spells at the beginning and during the growing season usually occur in the Upper East region and are sometimes known to have a detrimental effect on sorghum and millet crops.

Table 3 presents the minimum values, maximum values and standard errors of the mean and coefficients of variation of eight agronomic characteristics recorded during the two cropping seasons. Hundred seed weight, panicle width and panicle length showed the least variation. Number of days to 50% flowering ranged from 64 to 118 days with an average of 96 days. Accessions may be broadly grouped into three main categories with regard to number of days to 50% flowering: very early (less than 85 days), medium (86–105 days) and late (more than 105 days to 50% flowering). Using this classification, about a third (34%) of the accessions was considered early, 16% medium and 50% was late. A later survey conducted in the district in November 2005 showed that earliness is an important plant characteristic for farmers. This is because

Table 2. Rainfall at Manga Agricultural Research Station and Tesnatinga village in Bawku - East district during the 2003/2004 and 2004/2005 cropping seasons, respectively.

Months	Rainfall (mm)	
	2003/2004	2004/2005
June	128	175
July	151	161
August	336	183
September	327	51
October	87	18
Total	1030	587

Table 3. Range, means, standard deviation (SD) and coefficient of variation (CV) for eight agronomic characters of 55 sorghum accessions evaluated in the 2003/2004 and 2004/2005 cropping seasons (based on average values obtained from two seasons/locations).

Agronomic characters	Minimum	Maximum	Mean	SD	CV(%)
Days to 50% flowering	64	118	95.8	15.1	15.7
Plant height (cm)	128	432	301.7	77.1	25.6
Panicle length (cm)	15.0	42.5	27.7	7.0	25.2
Panicle width (cm)[1]	4.4	11.0	7.3	1.3	18.1
Panicle weight (g)	18.7	71.6	44.8	12.9	28.9
Threshed grain weight (g/panicle)	3.7	43.9	24.1	8.6	35.6
100 grain weight (g)[1]	1.5	3.6	2.6	0.4	15.4
Grain # per panicle[2]	250	2920	1354.2	491.8	36.3

[1] measured in season 2004/2005 only.

[2] assessment is based on calculation.

they have only one growing season in a year and the long dry season usually leads to food shortages. Farmers are anxious, therefore, to have early-maturing crops.

The common names of most of the accessions found within the early group were either Naga white or Naga. Naga white is the first variety developed by breeders in Ghana through mass selection, from a collection made in Ghana in 1967, and is reported to mature in 95 days (Schipprack & Mercer-Quarshie, 1984; Frölich & Buah, 1991). Even though Naga white is not a local name it is commonly used by farmers. Naga on the other hand refers to Naga red, introduced by the Presbyterian Agricultural Station in the district over twenty years ago. Other accessions within this early group, Jerry bumbalug (BED9) and Jerry (BED14), are the same, and both refer to Kapaala, except that the name Jerry is more commonly used by farmers from the Bimoba ethnic group.

A wide range (303 cm) in plant height was observed between the accessions with a minimum height of 128 cm, a maximum of 431 cm and an average height of 302 cm. Rao *et al.* (1996), however, reported heights of Indian sorghum varieties reaching 655 cm. Plant height in sorghum is another important characteristic for Ghanaian farmers because the stalks are used for fencing and roofing. Taller stalks are preferred over shorter types. Over 50% (data not shown) of the accessions were either tall (3–4 m) or very tall (above 4 m). Eyadema (BED60) was the shortest. It is said to have been introduced from a village across the Togo border.

The mean panicle length and panicle width were 28 cm and 7.3 cm respectively. With the exception of Torok (BED33 and BED50) all late-maturing accessions had long panicles (more than 30 cm), while all accessions with panicle length less than 25 cm were early maturing. The mean panicle weight and threshed grain weight were 44 g and 24 g respectively. Hundred grain weight ranged from 1.5 g to 3.6 g with an average of 2.6 g. Naga zula (BED20), Belko peleg (BED26), Gibrok (BED28), Torok (BED33 and BED50) and Nwuago (BED65) were found to have hundred grain weights exceeding 3 g.

Days to flowering, panicle width and hundred grain weight showed the least relative variation of the eight traits recorded. Threshed grain weight and grain number per panicle showed the highest relative variation.

Correlation coefficient analysis among agronomic traits

The correlation coefficients among agronomic traits for the sorghum accessions evaluated are presented in Table 4. Days to 50% flowering had a positive and highly significant correlation with plant height and panicle length. These positive correlations are based on the longer time available for leaf initiation, leaf appearance, internode growth and the production of flower primordia. Days to 50% flowering had a highly significant negative correlation with grain weight. This negative association is associated with the shorter time available for grain filling in the late-maturing accessions. Plant height had a highly significant positive correlation with panicle length and a significant positive correlation with panicle weight. Panicle weight was closely and positively correlated with threshed grain weight. No significant correlation was observed, however, between panicle length and panicle width, or between panicle length and threshed grain weight.

Agronomic characteristics: variety × environment interactions

The main effect of the accessions was highly significant (*P*<0.001) for all the agronomic characters assessed (Table 5). The environment main effects for all the agronomic characters assessed were also highly significant (*P*<0.001). Similarly the

Table 4. Simple linear Pearson correlation coefficients among agronomic traits measured in both growing seasons based on 55 sorghum accessions (excluding BED19 which was only observed in one season/location).

Agronomic characteristics	DFF	PlH	PaL	PaW	GW
Days to 50% flowering (DFF)	-	0.75**	0.65**	0.15	–0.85**
Plant height (PlH)		-	0.72**	0.29*	0.14
Panicle length (PaL)			-	0.11	0.02
Panicle weight (PaW)				-	0.91**
Threshed Grain weight (GW)					-

* significant at *P*<0.05; ** significant at *P*<0.01.

Table 5. Effect of Accession (A), Environment (E) and interaction (A × E) on the agronomic characteristics of sorghum germplasm evaluated.

Character	A	E	A × E
Days to 50% flowering	***	***	ns
Plant height	***	***	**
Panicle length	***	***	***
Panicle width	***	na	na
Panicle weight	***	***	**
Threshed grain weight	***	***	**
100 seed weight	***	na	na
Grain # per panicle	**	na	na

** *P*<0.01; *** *P*<0.001.

na: not applicable because measurements were done only in one environment.

Environment × Accession interaction effect was highly significant ($P<0.001$) for panicle length, and significant ($P<0.01$) for plant height, panicle weight and grain weight. However, the Environment × Accession interaction effect was not significant for days to 50% flowering. This indicates that with regard to days to 50% flowering the accessions responded in a similar way to the two environments. The rainfall regime early in the growing season was similar in the two environments. The early cessation of the rain in the second environment did not occur until after flowering. Thus it had no major effect on flowering.

Morphological characters of sorghum accessions

Morphological variation among accessions was high with regard to endosperm texture, panicle shape and compactness, glume and grain colour (Figures 1a–1h). Moderate variation was found in panicle exsertion and grain covering, while little variation was displayed in shattering.

The most frequent endosperm colour was yellow. In almost all accessions (90%) the grains had no lustre. Similarly, most of the accessions (95%) were pigmented with regard to plant colour while only a few (5%) were tan (non-pigmented).

Texture is the most important factor governing food quality. The distribution of accessions for endosperm texture gave a proportion of 35% for completely starchy and 14% for mostly starchy endosperm texture and 12% for corneous and 23% for mostly corneous endosperm texture. Thus starchy accessions formed a greater percentage of the total. This is an important reflection of the food uses of the sorghum varieties found in the district. Starchy grains are associated with high fermenting ability in brewing local beer which is very popular among the local people in the district. Since sorghum malt for brewing, and for making the thick and light porridges, are the most common uses for grain sorghum it is not surprising to find these types abundant in the collection. Kebede (1991), Ayana & Bekele (1998) and Abdi *et al.* (2002), in their studies on morphological variation of sorghum in two regions in Ethiopia, also found that a high frequency of sorghums with starchy endosperm existed in areas where fermented bread made with sorghum was extremely popular.

The most abundant glume colours were black (52%) and mahogany (32%). White and brown were the most frequent grain colours among the accessions evaluated. Yellow as well as red grains were also found. One accession, Niyirinchi (BED32), had a white grain colour with dark purple pigmentation. This variety is grown for medicinal purposes, as an antidote for dizziness. Farmers distinguish different types of sorghum on the basis of grain colour and these colour-based varieties also usually differ in their uses. White grains are preferred by farmers for their use in local food and porridge, because they give the desired colour when prepared. In the absence of

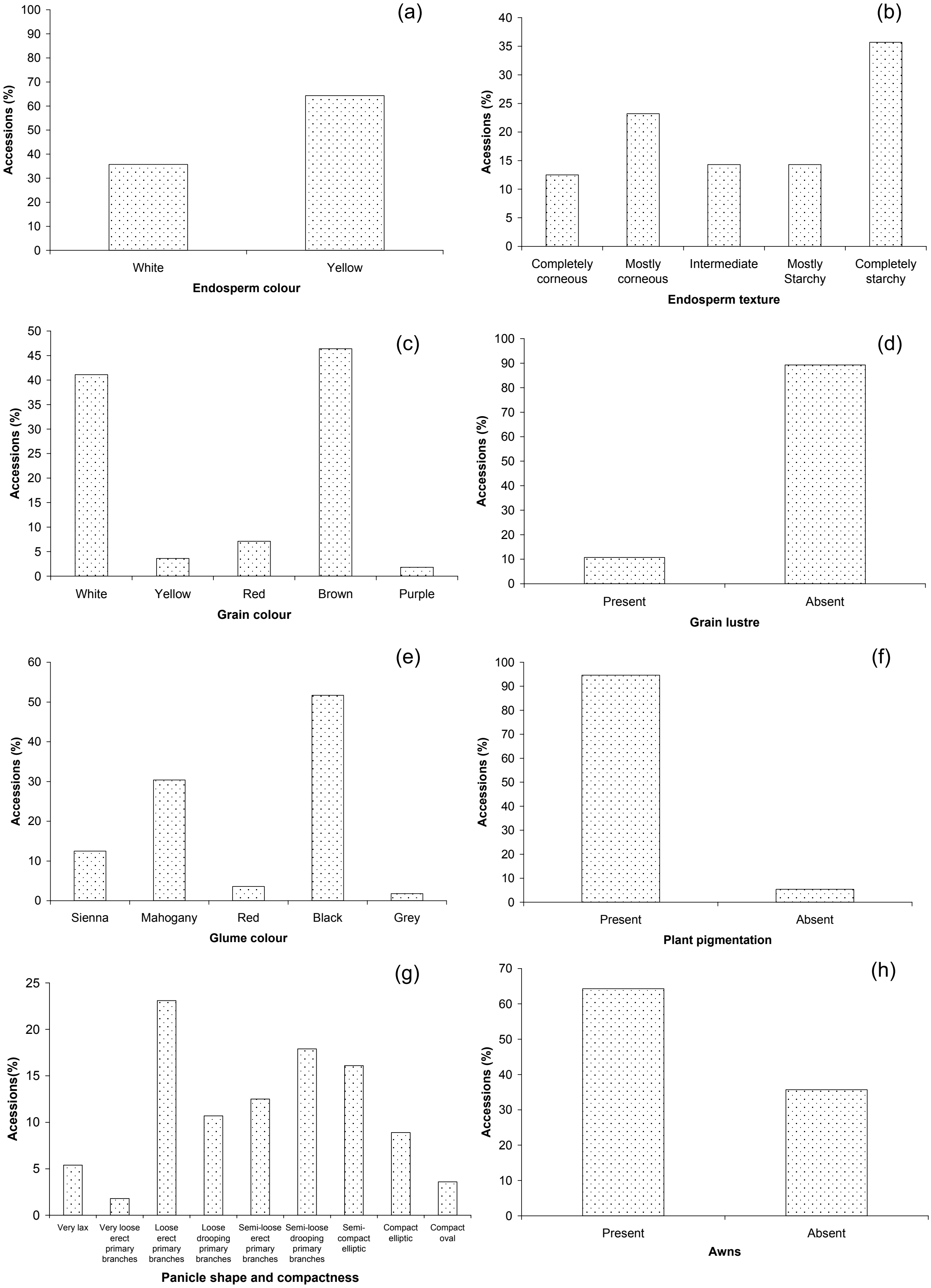

Figure 1. Distribution of sorghum accessions by (a) endosperm colour, (b) endosperm texture, (c) grain colour, (d) grain lustre, (e) glume colour, (f) plant pigmentation, (g) panicle shape and compactness, and (h) presence of awns.

bird damage or grain mould, good food quality is generally associated with white seed (Dogget, 1982). Brown and red grain, on the other hand, are preferred in Bawku East because of the characteristic dark colour it gives when used to prepare the local beer. Ayana and Bekele (1998) also observed a high variation for seed colour in their study of morphological variation of sorghum germplasm and suggested that their observation could be the result of both human and natural selection.

Panicle shapes from very lax to compact oval were found among the accessions. This distribution of different panicle compactness and shape also suggests the distribution of different races of sorghum (Dogget, 1988). The presence of semi-compact, very loose and open panicle types suggests the occurrence of caudatum, guinea and bicolor races. The loose and semi-loose panicle types with erect primary branches together constitute 36% and the loose and semi-loose panicle types with drooping primary branches constitute about 29% of the accessions.

There were more accessions with awns than without awns. Ayana and Bekele (1998) suggest that the absence of awns in sorghum may be associated with the ability to reduce evapo-transpiration in dry lowland areas. The presence of awns may reduce bird damage, as in rice (Richards, 1986).

Genetic diversity analysis

One microsatellite locus (Sb5-85) was excluded from the study because it failed to amplify consistently in all the 46 accessions. Fourteen primers were therefore used for the analysis. With the exception of SbAGH04 and Sb6-57 all the remaining 12 microsatellite loci were polymorphic (Table 6). The three microsatellite loci SbAGF08, SbAGDO2 and Sb1-10 amplified more than one band per genotype and eight accessions were found to be heterogeneous. All primers produced fragments varying from 100 to 200 bp in size. The number of alleles scored ranged between 1 and 8. The primer Sb1-10 detected the highest number of alleles. An average of 3.7 alleles per locus was detected using the 14 SSR primers, indicating an appreciable degree of genetic diversity between accessions. In their study to determine the phylogenetic diversity amongst 22 sorghum accessions using 28 SSR primers Agrama and Tuinstra (2003) detected an average of 4.5 alleles per locus. They suggested that because agarose gels have lesser resolving power than acrylamide gels their use could result in the detection of fewer numbers of alleles per locus.

Genetic variation among accessions

The UPGMA dendrogram discriminated among the accessions, sorting them into four major clusters at 70% level of similarity (Figure 2). The first major cluster consisted of four accessions: Tallas (BED48), Amanyeaw (BED46), Belko peleg (BED44) and

Table 6. SSR markers used for genotyping assays of 42 sorghum accessions.

SSR markers	No of alleles
SbAGE01	2
SbAGH04	1
SbAGF08	3
SbAGF06	2
SvPEPCAA	5
Sb6-57	1
Sb4-121	3
SBKAFGK1	2
SbAGB03	4
SbAGB02	5
Sb1-1	6
SbAGD02	3
Sb1-10	8
SbAGE03	7

Belko peleg (BED15). The last two accessions were found to have the same local name. All four accessions were late in phenology and tall with white or brown grains. The second major cluster consisted of six accessions (BED64, BED67, BED51, BED59, BED55 and BED7). They were mainly tall, early- to medium-maturing types, with red or brown grains.

The third major cluster consisted of the highest number (19) of accessions (Figure 2). A majority of these accessions had names such as Naga and Naga red. This cluster also consisted of early-maturing accessions of short to medium height. Within this cluster four sub-clusters, which appeared to be grouped according to grain colour, could be differentiated. BED 66 and BED 68, both with white grains, formed the first sub-cluster while BED16 (Naga white) remained ungrouped and formed the second. In the third sub-cluster four Naga red types; BED18, BED45, BED20 and BED22, all with red grains and black glumes, were clustered together. Among the accessions found in the fourth sub-cluster, BED60 (Eyadema) and BED61 (Kapaala) were found to be closely related. Interestingly their local names are used interchangeably by farmers, because farmers consider them to be the same, although they differ in height. However, Eyadema is an introduction from Togo while Kapaala was introduced from the research institute in Ghana in 1996. The two are believed to be the same introduction (ICSV111) from ICRISAT, but underwent further selection by the different national research institutes before being released as new varieties. It is a testimony to farmer acuity in sorghum selection that they recognize the similarity, here confirmed by marker analysis, despite different names.

Seventeen accessions aggregated in the fourth major cluster (Figure 2). These accessions, except for the accessions BED4, BED6, BED28, BED29 and BED33, are mainly tall and late-maturing types and are called Belko by the farmers. This cluster further separated at 73% similarity into two main sub-clusters; the first sub-cluster mainly comprised of brown grained sorghums while the second sub-cluster comprised red grained sorghums. Belko varieties of sorghum are the most commonly grown local varieties in the district and are usually given secondary names, e.g., Belko zia (brown/red belko) to distinguish between the types according to grain colour or texture.

Most of the relationships among the accessions shown in the dendrogram (Figure 2) are explicable in terms of agro-morphological data and information obtained from the farmers about their varieties. Nonetheless, in the case of BED33 (Torok) and BED50 (Torok), although agro-morphological data suggested a close relationship, the molecular analysis placed them far apart (in the fourth and second cluster, respectively).

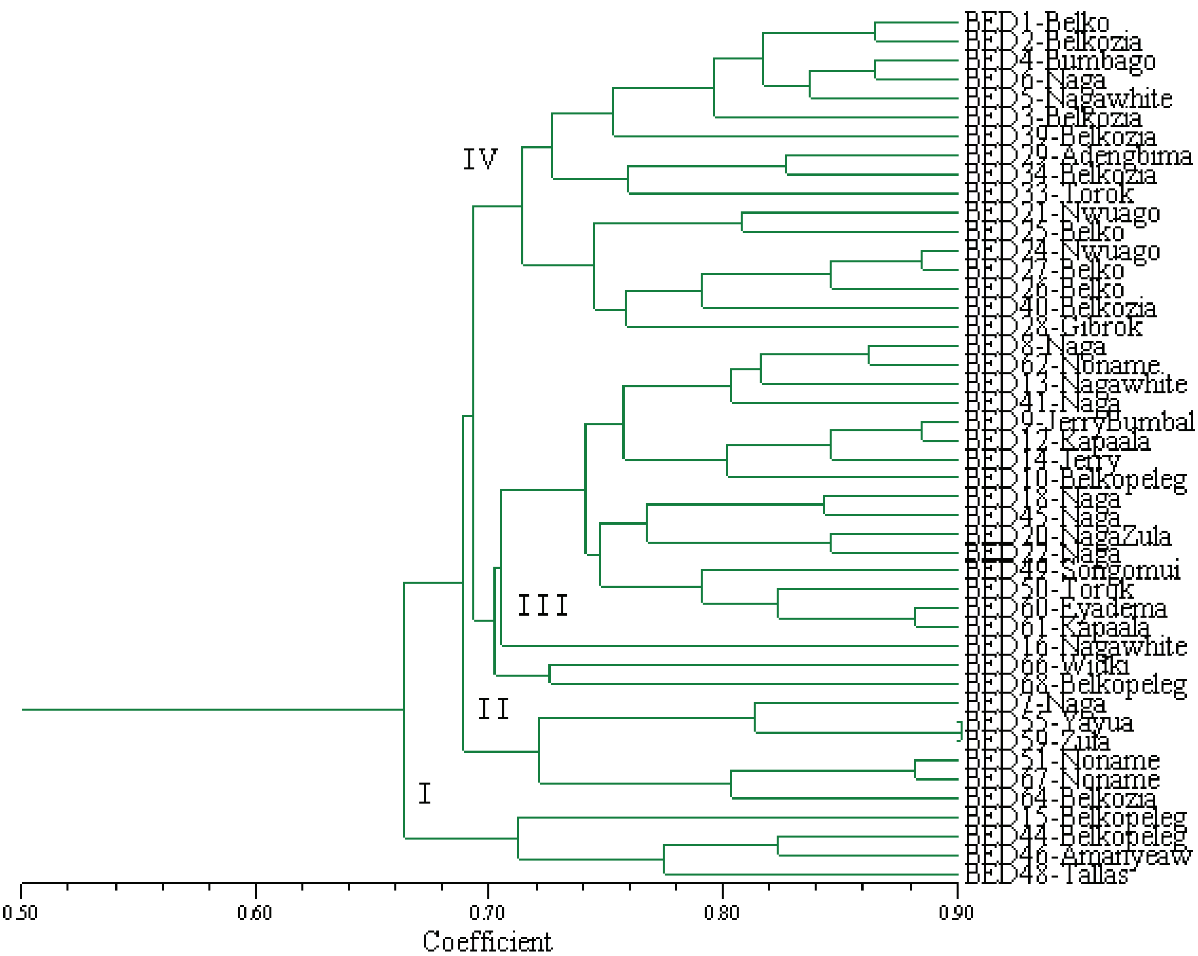

Figure 2. Genetic similarity among sorghum accessions revealed by UPGMA cluster analysis based on SSR data with the simple matching coefficient of SimQual method.

Genetic variation within panicles

The dendrograms in Figures 3–6 indicate the genetic similarity within the four panicles representing the accessions BED4, BED68, BED7 and BED19. Considerable variation was found within the panicles. Furthermore, the degree of within-panicle variation differed among the accessions. At 70% similarity level individuals in BED4R1-7 formed 6 clusters, BED68R1-5 formed 3 clusters while BED7R2-11 and BED19R1-10 both formed 2 clusters. This shows that variation within BED4R1-7 and BED68R1-5 was higher than for the other two panicles. All the four accessions assessed are late maturing; BED4 and BED68 have the same grain and glume colour, however, and are comparable in height and number of days to 50% flowering. BED7 and BED19 also share the same grain and glume characteristics and have the same height and number of days to 50% flowering.

In all four panicles there was one outlier which was distant from all the other individuals. This suggests that in each panicle there were some few individuals with traits distinct from the majority. The variation within each panicle corroborates observations made with farmers during our field learning experiment on variation in sorghum (Kudadjie *et al*., in press). In our investigation of the phenomenon of single panicle descent we encountered a few cases where a few seeds on a panicle had a different colour from the rest. Furthermore, seeds sown from the same panicle later showed differences in seed colour in some of their progeny. This underscores the importance of carrying out the molecular analysis.

The results from our molecular study show an appreciable amount of diversity for a predominantly self-pollinating species. A typical outcrossing rate is around 10%, both in farmer varieties and modern varieties of sorghum (Dje *et al.*, 1999; Pedersen *et al.,* 1998). However, it is not very surprising since 10–30% level of outcrossing has been reported in the more open panicles of the Guinean races of sorghum (Ollitreault, 1987 cited in McGuire, 2005).

The way farmers in the district manage their fields, the mixing of different varieties in the same field, and the distances between different sorghum fields, provide opportunity for gene-flow. In many instances fields owned by different farmers are only separated by foot paths. This closeness is due to severe land constraints. Gene-flow could arise from hybridization between different seed lots of the same variety or between different varieties. Different varieties will have the opportunity to cross if their flowering periods overlap. In sorghum, flowering lasts for 4–5 days on an individual plant, and because of the variation among individual plants with regard to flowering initiation, viable pollen can be available from a given variety for 10–15 days (House, 1985). Thus the period for availability of viable pollen will be prolonged where different fields are close to each other or have mixed varieties in the same field.

This also means that more crossing is likely to occur, leading to an increase in diversity within and among fields.

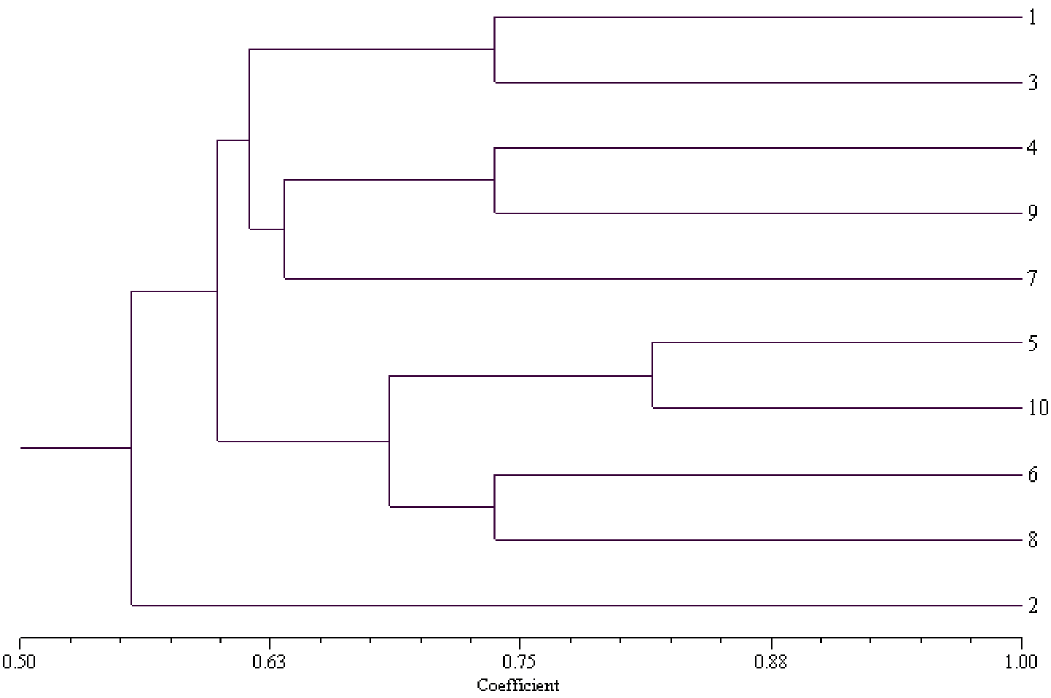

Figure 3. Genetic similarity within Panicle BED4R1-7 as revealed by UPGMA cluster analysis based on SSR data with the simple matching coefficient of SimQual method.

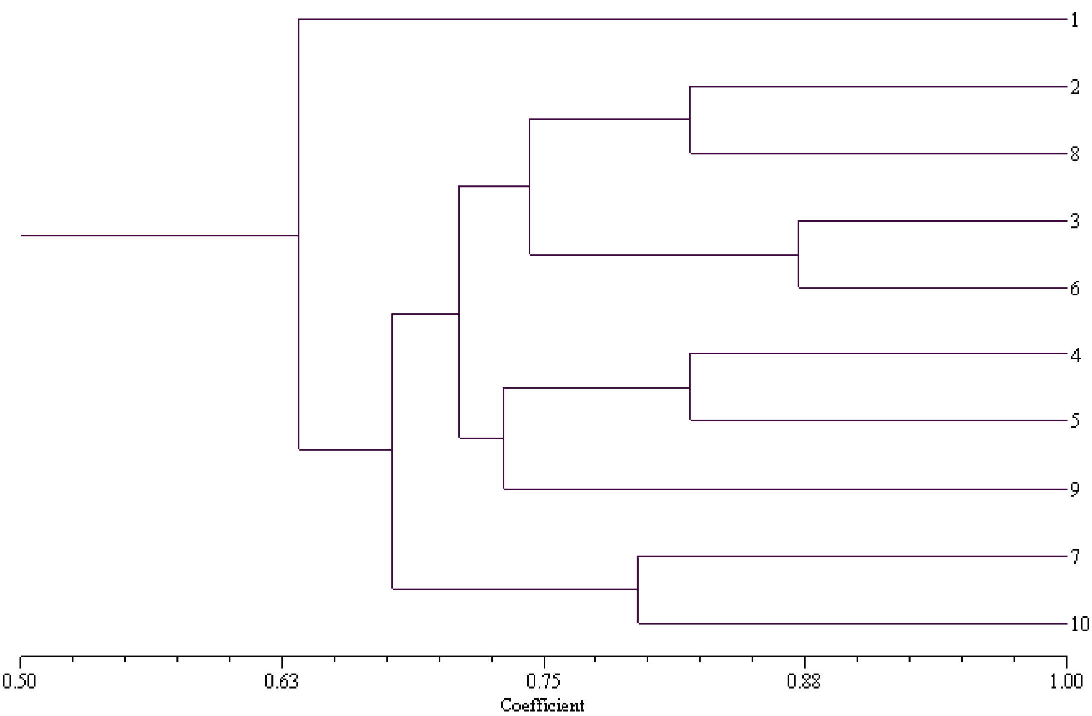

Figure 4. Genetic similarity within Panicle BED68R1-5 as revealed by UPGMA cluster analysis based on SSR data with the simple matching coefficient of SimQual method.

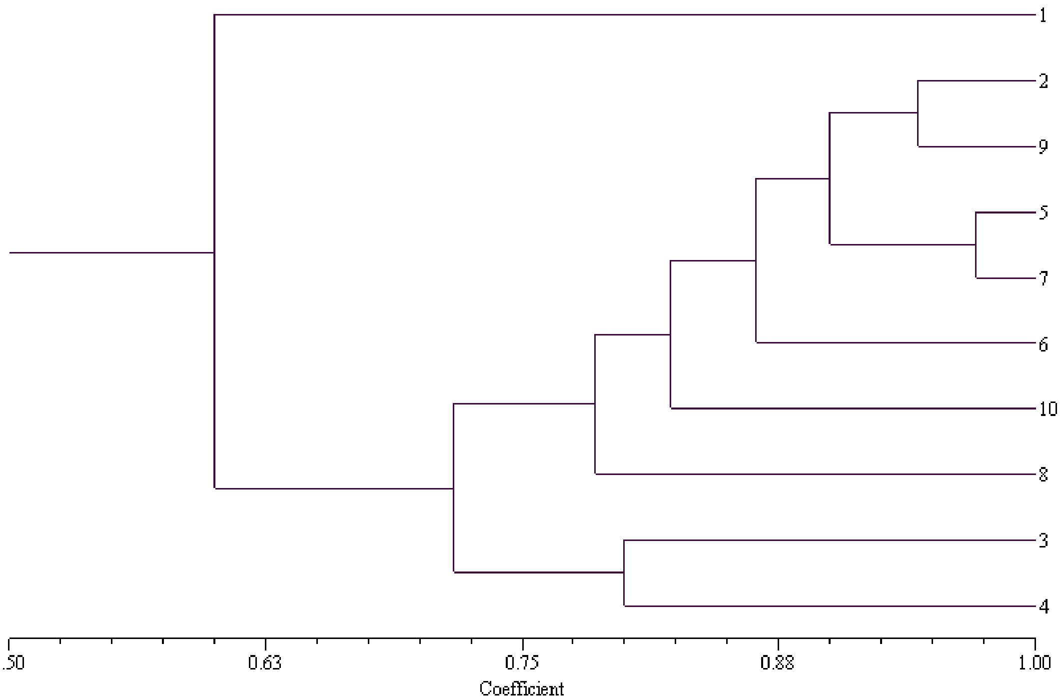

Figure 5. Genetic similarity within Panicle BED7R2-11 as revealed by UPGMA cluster analysis based on SSR data with the simple matching coefficient of SimQual method.

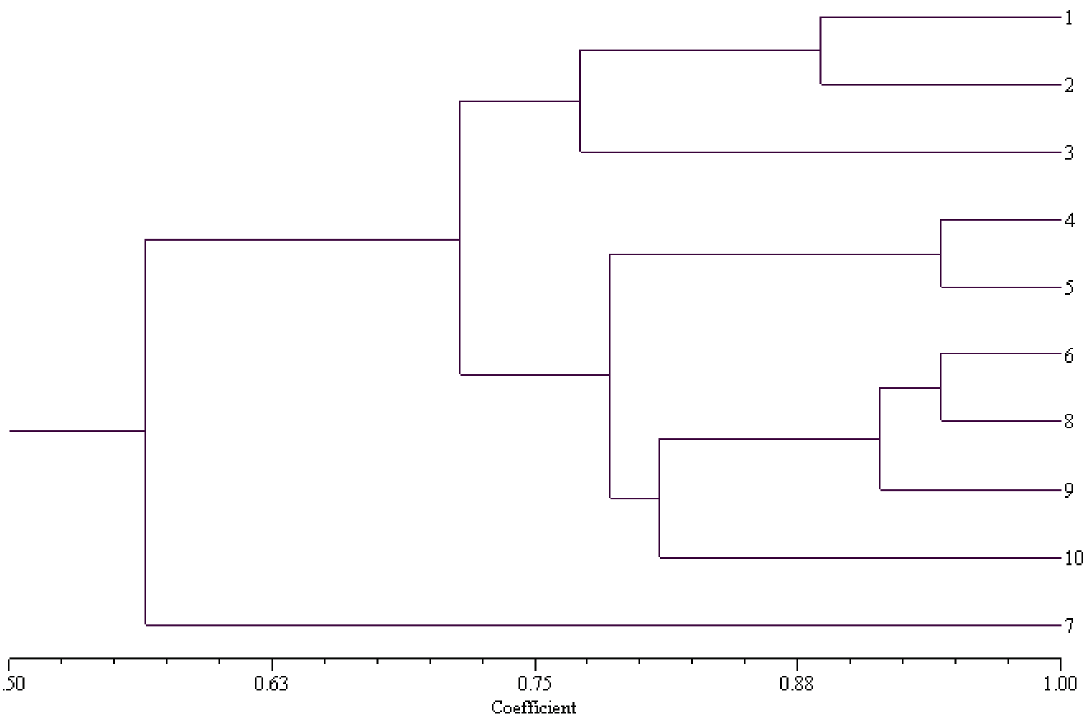

Figure 6. Genetic similarity within Panicle BED19R1-10 as revealed by UPGMA cluster analysis based on SSR data with the simple matching coefficient of SimQual method.

Conclusions

The study shows that considerable genetic diversity exists among the sorghum accessions collected from the Bawku East district in the Upper East region. The results of this study makes an important contribution to knowledge about sorghum diversity in the district, even though further work is needed to assess the genetic diversity in all three sorghum growing regions in the country.

The variation in days to flowering would be of extreme importance to farmers in this district, who experience a mono-modal rainfall pattern interrupted by drought. Crop improvement programmes can make use of this variability to develop varieties that fit within this agro-ecological niche.

The study has shown also that even for a species which is predominantly self-pollinated substantial diversity exists within panicles. The information obtained on these accessions will be useful for the conservation of the sorghum genetic resources in the region and the country more generally. There is the possibility of losing desired traits in certain genotypes if these are not maintained. The present information can contribute to safeguarding of farmer varieties through proper management and especially for those varieties preserved for specific purposes, and on which farmers place a high premium. Conservation of such varieties needs, in future, to follow selection and maintenance. This can be done by building on farmers' knowledge on genetic diversity, since it has been shown here that farmers are notably observant of and knowledgeable about varieties, e.g., in being able to recognize the singularity of a variety released under two different names.

CHAPTER 5

Understanding variation in sorghum through with-farmer experimentation*

C.Y. Kudadjie[1, 3,*], P.C. Struik[2], P. Richards[3], S.K. Offei[4] and P.B. Atengdem[1]

[1] Agricultural Extension Department, College of Agriculture and Consumer Sciences, University of Ghana, P.O. Box 68, Legon, Ghana.
[2] Crop and Weed Ecology Group, Wageningen University, Wageningen, The Netherlands.
[3] Technology and Agrarian Development Group, Wageningen University, Wageningen, The Netherlands.
[4] Department of Crop Science, College of Agriculture and Consumer Sciences, University of Ghana, Legon, Ghana.

Abstract
The need for an appropriate research strategy to build upon the knowledge of sorghum farmers in north-east Ghana in terms of diversity management and variety maintenance was identified in a previous diagnostic study. A joint experimental framework was established to encourage interaction between the knowledge systems of farmers and scientists. This chapter outlines the process and outcome of the joint learning approach adopted. Researchers and farmers used scientific experimentation both to investigate inter-varietal, intra-varietal, and random variation in sorghum. For better understanding and exchange of ideas, researchers sought to understand farmers' concepts of a variety and how they perceive diversity (i.e. researchers sought to enter into and interrogate the farmer knowledge system). Results provide evidence that farmers' management practices are shaped by local perceptions of diversity, and that systematic exploration of both scientific and local ideas, when aimed at points of convergence, might help farmers better to link their management practices to variation revealed through experimentation. It has been widely reported that African farmers are willing experimenters, but the present study offers specific evidence on the advantages of using a joint experimental approach to enhance farmers' capacity to understand complex phenomena associated with plant variation.

Keywords: diversity, experimentation, farmer's knowledge, genetic variation, sorghum.

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Introduction

Modern research and development, and formal centralized plant breeding, have tended to ignore, and in some cases undermine, the capacities of local farming communities to modify and improve plant varieties (FAO, 1999). At the same time, the role of small-scale farmers in the conservation and development of plant genetic resources is increasingly acknowledged (Almekinders & Elings, 2001; FAO, 2004; Howard, 2003). Historically, farmers have developed and maintained a diversity of crops and varieties in their farming systems. This ability is based on the knowledge they acquired about crops and their farming environment, as well as their understanding of socio-economic conditions (Bellon *et al.*, 1997; FAO, 2004; Friis-Hansen, 1999). Farmers acquire knowledge on plant genetic resources in several ways (Richards, 1995): by trial and error, by comparing the performance of different plant types, by planting mixed seed stocks and suffering or benefiting from the consequences, and by encountering new materials as a result of deliberate or accidental introduction.

Although farmer knowledge has been widely acclaimed, it has also been cautioned that it should not be idealized (Bellon, 2001). Farmers know a great deal about their own farms, but there are aspects they do not know or understand. For example, Bentley & Rodriguez (2001) reported that Honduras farmers' inability to grasp the concept of metamorphosis causes them to believe that weevils are generated spontaneously by the grain. Sometimes farmers also do not fully understand genetic diversity or crop improvement through selection. Louette & Smale (1998) found that maize farmers in Mexico had difficulty in understanding that varietal characteristics such as plant height can be modified through selection.

Over the past decade, participatory approaches to crop improvement (collaborative plant breeding), involving some form of interaction between farmer-breeders and formal plant breeders, have been developed (Ceccarelli *et al.*, 2001; Eyzaguirre & Iwanaga, 1996; Fukuda *et al.*, 2005). Among various implementations of the basic participatory idea, 'farmer-led' participatory plant breeding (McGuire *et al.*, 2003), is a form of interaction that seeks to support farmer genetic resource management through promoting general skills in crop improvement (Gomez *et al.*, 1996; Rice *et al.*, 1998; Saad *et al.*, 2001; Sperling & Scheidegger, 1996). But among farmer-led approaches that focus on changes in farmers' selection practices, a transfer of technology approach tends to prevail (McGuire *et al.*, 2003). For example, some projects have attempted to teach farmers' basic genetics and techniques through intensive, short duration training workshops (Gomez *et al.*, 1996; Rice *et al.*, 1998; Saad *et al.*, 2001).

However, in this study, we take an alternative approach to enhancing farmers' skills in genetic resource management. We focus on enhancing farmers' knowledge through a process of joint experimentation. Part of the aim is to improve farmer skills. But it is also an objective to seek common ground for researchers and farmers to interact more effectively (Soleri & Cleveland, 2001; Soleri *et al*., 1999) over genetic resource management issues. This chapter reports results of such a process of experimentation involving researchers and farmers working together in farmers' conditions. The experiment was devised after an initial period spent exploring farmers' knowledge concerning genetic variation in sorghum. A specific aim was to understand better the potential points of convergence and divergence in the thinking of farmers and scientists on genetic issues.

The work was carried out in the Bawku East district of north-east Ghana. Sorghum (*Sorghum bicolor* (L.) Moench) is an important traditional crop for a majority of rural communities in northern Ghana. The plant has multiple uses: the grain is milled for food, and used for the preparation of local beer, and as medicine for treating several ailments. Leaves are used for fodder and stalks supply fuel, fencing and roofing materials.

Sorghum is mainly self-pollinating but some out-crossing has been reported. For cultivated sorghum, out-crossing is often around 5−10% but the figure tends to be higher for sorghum types with loose panicles (Dogget, 1988). Out-crossing rates of 5−7% have been recorded in durra sorghum, a race with compact panicles, compared to 10−30% in the more open panicles of race guinea (Deu *et al.,* 1994; cited in McGuire, 2005).

Management and use of sorghum diversity by farmers was first assessed through a diagnostic study (Kudadjie *et al.,* 2004). Evidence of varietal mixtures in farmers' fields led to local discussions with farmers on their knowledge and practices concerning diversity management and variety maintenance (Kudadjie *et al.,* 2004). These discussions also provided insight into local levels of awareness of variation within and between their sorghum fields and how important farmers considered such variation to be. Most farmers displayed a general knowledge about the influence of genetic, environmental and temporal factors on plant variation. However, only a few appeared to know or understand these factors in detail and, therefore, the majority did not manage or make use of them systematically in their agronomic practices. The diagnostic study (Kudadjie *et al.,* 2004) showed that farmers usually did not mix varieties before planting, but some farmers did mix *Belko* types belonging to a local landrace. Sorghum heads are harvested in bulk by farmers and several panicles are selected for seed only after harvest. Consequently, phenomena such as single-panicle descent, within-variety variation, and plant-to-plant variation, were not very obvious to farmers. During discussions with farmers it became evident that most of them did not understand these sources of variation or doubted their occurrence in the field.

Based on an assessment of what farmers do or do not know and understand about anthropogenic and natural elements contributing to the creation or maintenance of variation among their crop types, and based on the questions emerging during discussions, an area of research was delineated with farmer input (Kudadjie *et al.*, 2004). A field experiment on variation was then designed with farmers to answer the questions that had arisen during this interaction:

- What plant characteristics show variation within a panicle-to-row population?
- What is the origin of the variation?
- How large are the variations observed within and between the varieties?
- Does the variation change from one generation to the next?
- How can the knowledge gained from this experiment be used?

In seeking methods to augment the knowledge of farmers, we found it necessary to understand their concept of a variety or genetic diversity and how they describe and differentiate between their varieties. The overall objective of this research was to contribute to farmers' knowledge on variation and to enhance their skills in managing their sorghum genetic resources by creating a field experiment for learning between farmers, and scientists. Specific objectives were:

- To identify characteristics used by farmers in differentiating between varieties.
- To understand farmers' perception(s) about variation and what they believe a variety to be.
- To demonstrate and investigate with farmers the phenomena of (i) inter- and intra-varietal variation and (ii) single-panicle descent.
- To assess the research approach and its contribution to farmer knowledge on variation, including convergence in farmer and researcher understandings concerning the possibilities of plant improvement via management of variation.

Methodology

This section describes the activities for planning and implementing the learning experiment with farmers. The entire research period extended from the end of November 2003 to December 2004.

Selection and composition of farmer research group

The farmers who participated in this research came from the two communities in which the diagnostic study (Kudadjie *et al.,* 2004) had earlier been undertaken, i.e., *Tesnatinga* and *Terago*. It was agreed with the farmers that important criteria for participation were their sustained involvement in the diagnostic study to ensure that they understood the direction of the research, and the commitment and interest required. Because of the extended period (5−6 months) of the diagnostic study the number of farmers participating in the discussions gradually declined. With the onset of the long dry season, many of the younger ones went south to look for jobs to sustain them until the next growing season. The remaining farmers were mainly older, but a few young ones occupied with dry season vegetable gardening remained with the process.

Specific selection of group membership was left entirely to the farmers from the two communities. It was, however, impressed upon the communities that they should ensure some gender balance in their selection. Numbers were limited to no more than ten farmers per community because a larger number would make the work more difficult. The initial composition of the group was five women and fifteen men but this later reduced to three and thirteen when two men and two women fell out due to poor health. Fourteen farmers were over 45 years of age and the remaining six were below 45 years of age (of the original group). All farmers were illiterate. The majority (16) were indigenes of the district and belonged to the main group (*Kusasi*). Two were *Busanga* and the remaining two *Mossi*. One of the latter was a migrant from Burkina Faso who had settled in the community about three years before the study commenced.

Planning of research activities with farmers

Meeting days

As the experiment was a season-long activity, it was important to choose regular meeting days and times for field activities. The mono-modal rainfall in the study area made farmers extremely busy during a short growing season. Time was of real significance to these farmers, who had to make the most out of their rain-fed agriculture within this period. Market days, which occurred twice a week, were excluded from meeting days. They were considered very important, not only for economic reasons but also for socializing. We tried different meeting times until we settled on the period between two and four o'clock in the afternoon. Although this was the heat of the day, and not considered a good time to be in the field by the researcher, it was preferred by farmers and was not negotiable. On average one meeting was held every 10 days. At the beginning of the season, fewer meetings/field activities were held but the frequency increased towards the end of the period since most of the observations were made from flowering to maturity of the crops. In total, 14 meetings were held.

Location of experimental plot

The location of the experimental plot was an important issue for farmers. Initially, farmers wanted one plot in each village so that we could also compare the results across villages but this was difficult to achieve, even though we offered to pay for the land. In the end it was agreed to use one plot close to our meeting place where the experiment would be easily accessible.

Data collection

The field observations to make and data to collect were determined through discussions with farmers. Following a farmers' visit to a research station where several sorghum accessions were being characterized (see below), a discussion was held with the farmers who undertook the visit. The plant characteristics they used in determining diversity and in distinguishing between the varieties on the station were discussed and a list was drawn up. This list was then discussed with all the farmers, and the plant characteristics on which observations were to be made were determined.

On-station visit

Before the planning and implementation of the experiment on variation, farmers were invited to visit a nearby out-station of the Savannah Agricultural Research Institute (SARI). The purpose was to show farmers some sorghum accessions collected from other farmers in the district, which were being grown for characterization. The visit was made at the end of the 2003 growing season when the crops were at the stage of maturity, prior to harvesting. Most farmers were heavily engaged in harvesting their own crops, therefore a representation of 11 farmers (3 women and 8 men) was selected. An extension worker, together with the researcher and assistant, also participated in this visit. A total of 38 sorghum accessions with a few duplicates were planted in single rows on the field.

Farmers walked through the plot and were free to discuss their observations among themselves. Using strips of cloth each farmer identified any ten accessions they considered different from each other by tying a strip on a plant within the identified row. After this exercise a discussion was held with farmers about what they had differentiated, and then to identify the basis for the differentiations they had made among the accessions. The information obtained through this visit was used as a basis for identifying, the plant characteristics considered important by farmers for determining sorghum diversity.

Methods employed in working with farmers

The main activities during meeting days were field visits and group discussions. The choice and sequence of topics for discussion were based on the growth stage of the crops in the field and the observations made by farmers during field visits. Discussions with farmers prior to the experiment showed the need to discuss seed selection practices, planting distances, flowering and floral structure and crossing in sorghum. Topics such as pollination and the structure of the sorghum flower were discussed with farmers when they could be easily seen in the field, and aided by the use of hand lenses. Discussions were combined with regular observations of the experimental plot.

Researchers visited farmers' homes or farms and sometimes other farmers in the village who did not participate in the research, to gain a wider perspective on the issues arising. Individual interviews with farmers were used to obtain further insight into perceptions about diversity. Dialogues with farmers were undertaken with the help of an assistant who understood and spoke *Kusal*. During the period of experimentation and at the end of the process, individual interviews were again used to (1) check whether farmers were following through with the activities, (2) to obtain their views about the results, and (3) to assess whether the experiment had contributed to their knowledge. In these interviews, we asked farmers what new knowledge or insight they had gained about variation, whether and why the knowledge was considered useful, and how it might be applied for managing the variation on their fields.

During the experiment, the farmers also received field visits from a sorghum breeder and an agronomist. These visits encouraged interaction and the exchange of ideas, and provided some early confirmation of the idea that joint experimentation is helpful in focusing interaction between farmers and researchers. After the experiment, farmers collectively shared their experiences in an open forum with many other farmers from their own and neighbouring villages.

Field experiment

Field layout

One hundred panicles (20 sorghum accessions × 5 panicles per accession), previously selected by farmers, were used for the experiment. Seeds from individual panicles were sown on a single row without mixing. Thus each row of plants represented a panicle and every 5 rows represented an accession. A row was 5 m in length.

Cultivation practice

The experiment was carried out in the 2004 cropping season under farmers' conditions and according to farmers' practices, which excluded the use of agro-chemicals from sorghum cultivation. Compost was evenly spread on the plot and ploughed into the soil on the 2nd of June and seeds were sown on the 4th of June. Each row was labelled and sown with the seeds from the designated panicle. The plant spacing used was 75 cm × 25 cm. Weeding was carried out whenever necessary.

Data collection
The following plant characteristics were recorded together with the farmers: plant height, plant pigmentation, panicle exsertion (distance between the flag leaf and base of the panicle), panicle shape and compactness, grain colour, glume colour, and axillary branching of stalks. All observations made by farmers were qualitative. Plant height and plant colour were assessed after flowering but before maturity. Panicle exsertion, axillary branching and panicle shape were assessed at maturity, while grain and glume colours were assessed immediately after harvesting to enable a closer inspection of the panicles. During field observations, farmers tagged any plant they considered different from other plants within the same row. The reasons for tagging plants were also noted by the researcher.

Data recording and analysis
Researchers first wrote down the accession and panicle numbers. Farmers then used symbols to represent the different characteristics that were observed. Farmers used a single stroke to denote uniformity in the characteristic assessed. Thus one stroke in the column under glume colour signified that within the same row of plants only one colour was observed and, therefore, with regard to glume colour, they were considered all the same. For panicle shape, grain colour and glume colour the number of strokes were not only used to indicate uniformity or variability, but also the extent of variability. This means that where farmers observed three different grain colours within a row they placed three strokes in the cell. Because of lack of literacy on the part of farmers, quantitative measurements such as plant height and panicle exsertion could not be taken using rulers. Such measurements were therefore based purely on farmers' perception and were quite subjective. In some cases the assessments of plant height were made relative to the heights of other varieties. For each characteristic that was assessed, the total number of accessions that showed variation was counted and the results were used to plot histograms. This enabled farmers to have in summary form an overview of the results we obtained. Efforts were made to ensure farmers understood what information the graph conveyed.

Results and discussion

Plant characteristics used by farmers to assess diversity
The interaction with farmers during the visit to the on-station plot provided insight into the plant characteristics that some farmers use to determine varietal diversity. Varietal diversity here refers to the range of different varieties (as named by either breeders or farmers), types, or landraces of the same crop (Longley, 2000). The characteristics

indicated by farmers during the discussions and meetings were plant height, axillary branching, panicle length and width, panicle exsertion, panicle shape and compactness, and grain colour. But in the farmers' own fields the most commonly mentioned were the grain and panicle characteristics. After harvest, when farmers had another opportunity to examine the panicles more closely, glume colour and grain hardness were further added to the list of characteristics. Older female farmers were found to bite into the grains to determine the texture and ascertain that the names they had originally mentioned were correct.

During the experimentation with farmers other characteristics, like plant and leaf pigmentation and length of internodes, were also mentioned as distinguishing traits. They related the length of internodes to the height of plants and suggested that shorter internodes were characteristic of shorter varieties while longer internodes were associated with taller varieties. They also associated the presence of pigments in the leaf and stalks with dark coloured grains while the absence of pigments depicted lighter or tan coloured grains. According to House (1985) a red pigment appears in the dead leaves and sheaths of red-seeded sorghum varieties but not in white-seeded ones. It is also known that the dwarfing effect of recessive genes which control height in sorghum causes the length of the internode to be reduced, but not the peduncle length, head size or leaf number. Axillary branching was mentioned by farmers as a trait common to some sorghum varieties. It is referred to as *kikris* or 'twins' in the local language when one or two panicles form in addition to the main panicle. It was found out during the experiment that this trait was not a sharp distinguishing feature used by farmers in their assessment, although they observed the phenomenon.

Bellon *et al*. (1997) noted that although farmers cannot observe the genetic structure of the crop, they gain knowledge of the morphological traits that are expressed. This knowledge, in turn, is used in their decision-making processes regarding their management of diversity. It was found that each characteristic used by farmers forms a part of the descriptor lists developed by the International Board of Plant Genetic Resources for breeders in characterizing and evaluating sorghum germplasm (IBPGRI/ICRISAT, 1993). According to Smale *et al.* (1999), classification of maize varieties in Mexico based on farmers' morpho-phenological descriptors was found to have a strong relationship with the taxonomy developed for maize by Welhausen *et al.* in 1952. This taxonomy system was itself found to be derived from farmers' descriptions. In short, the present study confirms earlier findings that there is good convergence between farmer knowledge and scientific descriptors on a morphological level.

Farmers' concept of a variety

Findings from the diagnostic study on the local names of sorghum used by farmers indicated that farmers apply some form of classification. According to Douglas (1975) classification is an essential aspect of how humans make sense of the world in which they exist; classification is in this sense socially-constructed (i.e., it is an aspect, in this sense, of how farmers organize farming and not given in nature). For this particular study it was considered useful to understand the local system of classification using the farmer naming system(s) and descriptions in order to explain local conceptions and perceptions of a variety. We found out that no specific word for sorghum exists in the *Kusal* language. Instead the word *ki* refers to sorghum and millet in general. This may be because they are both traditional non-leguminous grains and are used for similar purposes. Therefore, in discussing sorghum we always had to be specific by mentioning a sorghum type by name to avoid any misunderstanding.

Farmers use two names to denote their local sorghum types. The first, which may be termed as collective or first level names, are referred to by some as *budi*, which means 'clan' in *Kusal*. The word *budi* refers to a distinct group within a tribe and is normally distinguished by the name of the male ancestor from whom all fellow-clansmen trace their descent (Fortes, 1945; Rattray, 1932).

Belko is an example of a collective name assigned to sorghums according to specific features of the 'eye'. The grain and glume are together referred to as the eye in the local context while the panicle and panicle exsertion are referred to as the head and neck respectively. Interestingly, the simplified classification of cultivated sorghums and their closest wild relatives, developed by Harlan & de Wet (1972) for plant breeders, is also based on spikelet (i.e., glume and grain) types.

Second level names then describe variants within the collective group, sometimes by seed colour (e.g., *Belko peleg* = white Belko; *Belko zia* = brown Belko) or grain texture (e.g., *Belko dubrug* = corneous Belko). It should be pointed out here that the *Belko* type excludes all early-maturing types of sorghum whether considered a farmers' variety or introduced variety. (Some introduced sorghums which have been cultivated in the area for over 30 years are now considered by many farmers as their own variety). Among the early-maturing sorghum types cultivated by farmers, three red-seeded types generally called *Naga* (also considered another *budi* or 'clan') are distinguished mainly by the panicle architecture and stalk height. Based on these two characters the names *Guduru*, *Kokosbog* and *Zula* are assigned to the variants within this clan. To a lesser degree, seed shape, seed size and leaf size are used by some farmers but there is no general consensus with regard to these characteristics.

Other names were found to be more localized in their use and did not provide any extra information beyond a specific trait of the crop or how it is used. They might be likened to the position of strangers with no fixed position within the system of *Kusasi* clans, but with some kind of functional position (e.g., 'trader'). Examples of such functional categorizations include: *Kikamar* = sweet stalks and *Widki* = horse millet. Some other names in use do not seem to fit into either the systems based on descent or function. These proved confusing for the researchers. They were mainly late-maturing sorghums, not grown in the plots but described by farmers during interviews. Some classified them as *Belko* because they also possess hard grains. Others did not, explaining that there were slight differences in the maturity period. These sorghums may have been introductions or recent arrivals, not yet assimilated into any classification due to patchy or idiosyncratic usage.

Clearly, local thinking about plant types seems to be related to local thinking about social relationships. The following summary picture can be painted: sorghums in general are viewed as one large group (i.e., a tribe), while different types or varieties are viewed as distinct sub-groups (i.e., clans within the tribe), and these are further identified by using the second level names (equivalent to family/surnames or functional names).

In spite of the variants explained above all *Belko* types are considered the same by some farmers and it is therefore not surprising to find in such a farmer's field a deliberate mixture of *Belko* types with the explanation '*de wosa ane belko*', meaning they are all *Belko*. The naming and classification used by farmers may thus be linked to whether they perceive these varieties as similar, closely related, or very different and this may also determine how they are managed. McGuire (2002) suggested that in Ethiopia apparent differences in knowledge and practice in variety naming may indicate or even lead to variation in management.

Phenomena of variation

The information provided below covers observations that farmers made of the experimental field and how they used them to analyse and draw conclusions on different types of variation.

Variation between varieties/accessions

The 20 accessions evaluated were all late-maturing varieties and flowered within a given period. Farmers found it easier to make clear distinctions between the different accessions after they flowered. A majority were classified as *Belko* but were distinguished from each other using the second level names described. Once again it was observed that farmers mainly used the panicle and grain characteristics and in some other cases the pigmentation on the leaves and stalks and the plant height.

Table 1 shows the characteristics used by farmers in distinguishing between accessions and the descriptions they used.

All the *Belko* types were either described as tall or very tall. One accession, *Kyerig*

Table 1. Farmers' descriptions and comments on variations observed among sorghum accessions/varieties evaluated in a field experiment.

Accession number	Local name	Plant characters described and commented on by farmers				
		Grain colour	Panicle shape	Plant height	Panicle exsertion	Plant pigmentation
38R2	Belko	White	Drooping	Tall	Long	Black
02R2	Belko peleg	White	Drooping	Tall	Very long	Black
10R1	Belko peleg	White	Drooping and loose	Tall	Long, with axillary branches	Black
15R1	Belko peleg	White	Drooping	Tall	Very long	Black
19R1	Belko peleg	White	Erect and loose	Tall	Long	Black
23R1	Belko peleg	White	Drooping and loose	Tall	Long	Black
26R1	Belko peleg	White	Erect and loose	Very tall	Long	Red
40R2	Belko peleg	White	Compact, erect and short	Tall	Long, axillary branches	Black
43R1	Belko peleg	White	Loose and drooping	Tall and uniform	Long	Black
44R1	Belko peleg	White	Drooping and open	Tall	Very long	Black
54R2	Belko peleg	White	Drooping, few others erect	Tall and uniform	Long	Black
68R2	Belko peleg	White	Drooping	Tall	Long	Black
25R1	Belko zia	Brown	Generally loose and drooping, others erect	Tall	Long	Black
64R2	Belko zia	Brown	Mainly drooping but some erect	Tall	Long, but shorter than Belko	Red/yellow
65R1	Kyerig	White	Erect and loose	Short	Short	Black
32R1	Niyirinchi	Red/white	Loose and open	Short(er) than Belko	Short, starts at flag leaf	Black
01R1	Nwuago	Red	Drooping and loose	Tall	Long	Red
21R1	Nwuago	Red	Drooping	Tall	Long	Red
48R1	Nwuago	Red	Erect and loose	Tall	Long, axillary branching	Red
50R1	Torok	White	Short, compact and erect	Shorter than all others, variable	Short	Red

(65R1) was described as short while *Niyrinchi* (32R1) was said to be shorter than the *Belko* types. *Torok* (50R) was also said to be shorter than all the other accessions and by implication the shortest of all. After comparing their assessment of height to the actual measurements taken, the following pattern emerged; plant heights between 4–5 m were considered very tall and/or tall, heights between 3.2 m and 3.9 m were considered to be of a medium height, while heights between 2.9–3.2 m were considered short. Plants between 2.2 and 2.8 m were considered very short. To regard these categorizations as standard, however, may be quite misleading as the accessions excluded the very short types found among the improved/introduced varieties of sorghum. These height-based groupings should therefore be regarded as relative and thus likely to change if the range of plant heights to be assessed changes.

Within-variety and within-panicle variation

The investigation of the phenomena of within-panicle variation, random variation, and single-panicle descent required a much closer observation of individual plants per row. Table 2 shows how farmers recorded their observations on paper (see Section *Field experiment* for explanation). Variation in panicle sizes (length and width) and in plant height was very common among plants from the same panicle. Some farmers considered the plant-to-plant variation in panicle size and plant height to be deceptive and not a reliable character on which to base conclusions on variation. They explained that such variations were to be expected and easily arise due to differences in soil fertility or soil water conditions. McGuire (2002) also found that Ethiopian sorghum farmers had similar perceptions of the relative influence of the environment on traits such as head size and plant height. In Ethiopia farmers expected both traits to vary because of variation in soil conditions, rain, or management while expecting that planting on a uniform field with uniform, optimal management would produce little variation.

Differences in plant height were very pronounced in cases where some plants had been thinned to refill empty stands within the same row. Some plants of the accessions 40R2, 15R1, 65R1 and 25 R1 were attacked by shoot flies and this resulted in stunted growth. However, in two accessions some plants showed marked differences in height compared to the other plants within the same row, and these differences the farmers did not attribute to the environment. They described a very tall plant from accession 32R1 as ‘not belonging to its clan’ though most of its features conformed to those of the other plants from the same panicle. This off-type did not set any seeds after flowering. Another very tall plant from 50R1 was considered an off-type because while its glume colour and panicle shape were similar to the other plants within the same row, its grain colour, panicle exsertion and compactness were different. Some were of the opinion that this came ‘from the seed itself’, meaning that it could not be

Table 2. Variation in plant characteristics observed within (i) each panicle and (ii) variation within an accession. Data on accessions that show little or no variation in any of the five panicles is not provided. A single stroke means the character is uniform and two or more strokes mean it is variable. In the case of panicle shape, glume colour and grain colour the number of strokes also shows as many differences as were observed in the character.

Accession number	Plant characteristics observed by farmers					
	Glume colour	Grain colour	Panicle exsertion	Plant height	Panicle shape	Axillary branching
02R2	/	/	/	/	/	/
	/	/	/	/	/	/
	//	///	/	/	/	/
	///	////	/	/	/	/
	/	/	/	/	/	/
10R1	/	/	//	/	/	/
	//	/	/	/	/	//
	/	/	/	/	//	/
	//	/	/	/	/	//
	//	/	/	/	/	/
19R2	/	/	/	/	/	/
	/	/	/	/	/	/
	/	/	/	/	/	/
	/	/	/	/	/	/
	/	/	/	/	/	/
23R1	/	/	/	/	/	/
	/	/	//	/	/	/
	/	//	/	/	/	/
	/	/	/	/	/	/
	/	/	/	/	/	/
40R2	//	/	/	//	/	/
	/	/	/	/	/	//
	/	/	/	/	/	//
	/	/	/	/	/	//
	/	/	/	/	/	/
43R1	/	/	/	/	/	/
	/	/	/	/	/	/
	//	/	/	/	/	/
	/	/	/	/	/	/
	//	/	/	/	//	/
44R1	/	/	/	/	/	/
	//	/	/	/	/	/
	//	//	/	/	/	/
	/	/	/	/	/	/
	//	//	/	/	/	/

Table 2. Continued.

Accession number	Plant characteristics observed by farmers					
	Glume colour	Grain colour	Panicle exsertion	Plant height	Panicle shape	Axillary branching
68R2	//	/	/	/	/	/
	//	/	/	/	/	/
	/	/	/	/	/	/
	//	/	/	/	/	/
	/	/	/	/	/	/
25R1	/	/	//	/	/	/
	/	/	/	/	/	/
	/	//	/	//	/	/
	/	/	/	//	/	/
	/	/	/	/	//	/
64R2	/	/	/	/	/	/
	/	/	/	/	//	/
	/	/	/	/	/	/
	//	//	/	/	/	/
	/	//	/	/	/	/
65R1	/	//	/	/	/	/
	/	//	//	//	/	/
	/	//	/	/	/	/
	/	//	/	/	/	/
	/	//	/	/	/	/
01R1	/	//	/	/	/	/
	/	/	/	/	/	/
	/	//	/	/	/	/
	/	//	/	/	/	/
	/	//	/	/	/	/
21R1	//	//	//	/	/	/
	/	/	/	/	/	/
	/	//	/	/	/	/
	/	/	/	/	/	/
	/	//	//	/	/	/
48R1	/	/	//	/	//	//
	/	/	//	/	//	/
	/	/	/	/	/	/
	/	/	/	/	/	/
	/	/	/	/	/	/
50R1	/	/	/	/	/	/
	//	//	/	//	//	/
	//	//	//	//	/	/
	/	/	/	/	/	/
	/	/	/	/	/	/

attributed to human or physical mixtures but was inherent in the seed. This might be counted evidence of an intuitive apprehension of the existence of some genetic mechanism, though without implying (of course) that farmers have any inkling of Mendelian inheritance.

Apart from height differences, farmers also recorded differences in glume colour, grain colour, panicle exsertion, panicle shape and compactness. Variations in glume and grain colour were the most frequently found in plants grown from seeds of the same panicle. Bellon *et al*. (1997) noted that the strongest evidence of morphological polymorphism within traditional varieties relates to grain and panicle traits, which are most easily observed in the field.

From at least one out of every five rows/panicles, farmers indicated different glume and grain colour for plants in the same row. In one out of every ten rows differences in panicle shape/compactness were also found to occur for plants in the same row. Most of the variations observed in panicle shape and compactness were attributed to poor seed set except in a few cases (50R1 and 25R1). The panicles considered different were those which were erect and did not conform to the expected droopy nature of the others in the same row.

Single-panicle descent phenomenon

Table 3 shows how the grain colour of sorghum accessions sown in the experiment was used to study the single-panicle descent phenomenon. Only the accessions in which changes occurred in grain colour are presented. In nine out of the 20 (45%) accessions evaluated, such variations were observed. The rest maintained their grain colour without showing any variation. In the accessions which showed variation another grain colour was found among their progeny in addition to the colour shown by the parent. Where two different seed colours were observed, the more dominant one is indicated first as in 01R1, followed by the less dominant. In one case (65R1), the grain colours of the progeny did not always conform to the original colour of the seeds from the parent panicle. These observations provided opportunity to discuss again pollination in sorghum, synchrony in flowering dates, proximity, and mixtures of varieties by farmers as potential causes of variation.

All farmers attested to the fact that variation did exist among plants from seeds of the same panicle but they further noted that the 'mixtures' were much fewer than earlier observed when they threshed several panicles together to plant. Because this was visual evidence it was easy for farmers to appreciate the outcome. They all agreed that it was possible to reduce variation within their plant population if they select seeds or panicles that are uniform. However, a complete elimination of mixtures or variation was considered impossible.

Table 3. The phenomenon of single-panicle descent as shown through grain colour. Accessions from which no panicle showed differences in grain colour are excluded.

Accession Number	Panicle number	Colour of grain	
		Parent	Progeny
02R2	1	White	White
	2	White	White
	3	Buff	Buff, white
	4	White	White
	5	Buff	White, buff
23R1	1	White	White
	2	White	White
	3	White	White
	4	White	White
	5	White	White, brown
43R1	1	White	White
	2	White	White, brown
	3	White	White
	4	White	White
	5	White	White
68R2	1	White	White
	2	White	White
	3	White	Brown
	4	White	White
	5	Red	White
25R1	1	Brown	Brown
	2	Brown	Brown, white
	3	White	White
	4	Brown	Brown
	5	White	White
65R1	1	Brown	Brown
	2	Brown	White
	3	Brown	Brown
	4	Brown	White
	5	Brown	Brown
01R1	1	Brown	Brown, white
	2	Brown	Brown, white
	3	Brown	Brown, white
	4	Brown	Brown
	5	Brown	White, brown
21R1	1	Brown	White, brown
	2	Brown	White, brown
	3	Brown	Brown
	4	Brown	Brown
	5	Brown	Brown
50R1	1	White	White
	2	White	White
	3	White	White, buff
	4	White	White
	5	White	White

The research approach

The approach taken for conducting research with farmers was comparable to that suggested by Salazar (2002) for working with farmers on plant genetic resources. It tried to affirm existing farmer knowledge as a platform upon which to build rather than to replace it. The methodological principle is one of praxis, i.e., the action-reflection process of gaining knowledge (Greenwood & Levin, 1998; Gustavsen, 2001; Reason & Bradbury, 2001). The process aims to provide farmers with experiences through experimentation, which then serve as a basis for questioning or affirming existing knowledge, as a necessary step in gaining new knowledge. The approach is similar to others in which farmers have been helped to learn through experience-based or discovery learning (Leeuwis & Van den Ban, 2004; Van de Fliert, 1993) but makes explicit use of a formalized mode of experimentation using measurement of a kind recognizable to science. It is sometimes assumed that a formalized approach is closed to farmers lacking a school background. The present study shows otherwise. As Lave (1985) has demonstrated, a formal education is not a prerequisite for handling quite complicated computational and comparative operations but also that environment and practice are crucial to the way such computations are undertaken. Shoppers in supermarkets (to use her example) carry out complex computations necessary to compare values using the layout of the goods and shelving. They think 'with' the environment. What we have shown in the above account is that farmers can readily enter an experiment, and understand its implications, provided it makes sense in terms of their environment and practices. Convergence of knowledge systems requires an adequate theory of practice, based on a detailed knowledge of how farmers carry out observations already, and how these observational frameworks can meaningfully be extended.

The methods employed in working with farmers such as group discussions, field activities, informal interviews and follow up visits during our experimentation enabled them to share their views freely, and to participate discursively as well as practically. Farmers were eager to participate in the field activities except in cases where it was too strenuous for aged farmers. Field visits, and meetings with other stakeholders, such as field workers and staff of the Ministry of Food and Agriculture, scientists (an agronomist, soil scientist, plant breeder) from the research institutions, provided rare opportunities for close interaction and the fora for much needed exchange and knowledge sharing. Despite illiteracy farmers found that use of symbols to record observations enabled them to actively participate in discussions of results. They proved adept at using these same symbols to explain this research to illiterate farmers and schooled researchers alike.

According to Richards (2003, p. 2), "Technology development has to be conducive to the emergence of new social understandings and shared commitments, i.e., it has to contribute to the building of social solidarity. If technology remains sociologically alien then it will tend to destroy rather than transform and emancipate.” During our follow-up interviews with the farmers, they told us that experimenting together as a group helped them to develop a sense of belonging and strengthened existing ties between farmers from the two villages. This cohesion went beyond our agricultural activities to the show of concern and support in several cases. Contributions and gifts of food and drink were sometimes made to bereaved farmers and visits were made to those who fell ill. These acts may not be very different from the norm in other groups except that they were done by and for members of the experimenting group, and were thus expressive of a solidarity based on technological experimentation. Long ago Emile Durkheim (1912) pointed out that science cannot correct opinion. By opinion he meant the collective representations that spring from membership in a social group. If science cannot alter the beliefs based on social solidarity then society needs to reshape its beliefs around participation in group activities with scientific or technological content. This idea, we would suggest, should be central to the concept of the farmer field school. The science content of such activity serves not only a utilitarian function but also as the basis for new forms of rural social cohesion. What was certainly different for some farmers was the increased acceptance and recognition from community members because of their link with the group. An example is that of the migrant farmer from Burkina Faso, who experienced more respect in the village and obtained greater assistance from others when he had problems. This, he attributed to belonging to the experimental group. Some also told us about how other farmers in the village tried to forge friendships with them at local drinking spots, or with the women while processing their grains, all in an attempt to become privy to what they did and discussed during group meetings. Through this experimenting, farmers gained friends. Science and society merged at village level.

Contribution to knowledge and how knowledge would be used

A key objective in developing a viable theory of village experimental practice, based on investigating phenomena of plant variation together with farmers, was to contribute to their knowledge on variation and enhance their skills in diversity management. Through individual and collective feedback from the experimenting farmers we assessed whether and how this objective has been achieved. At the beginning, farmers did not know whether differences would be observed at all among plants grown from seeds from the same panicle and many were doubtful. At the end, all farmers acknowledged that intra-varietal variations do occur, citing examples of differences in grain colours, glume colours, panicle exsertion, shape and compactness. An important observation they made was that ‘mixtures’ could not be eliminated, but were fewer than when they threshed several panicles together for planting. They further deduced that to reduce mixtures in their own fields they would have to change their selection methods. As a farmer put it "We were always selecting our seeds based on how clean the seeds on a panicle looked and whether that panicle is big and clean, but not based on uniformity in seed colour. So our seeds are always mixed". Another farmer was of the opinion that before harvesting, removing 'different panicles' from one's field before bulk harvesting would help to reduce mixtures in their seed lots and in their fields. Farmers also noted that, if they did not mix their seeds they would maintain a pure trait (such as seed colour) in their varieties and obtain a higher market price for their grain.

Prior to the experiment, farmers attributed all mixtures (variation) to the work of God. Some farmers did not change their perception after the experiment. Indeed that was not our objective. During the experiment one old farmer remarked that it was not possible to know all of God's work and explain everything. However, another farmer, who was about 40 years younger, pointed out that through testing (experimentation) and observation they could know what they did not know and learn from it. At the end of the experiment, a large proportion (about two thirds) of the farmers acknowledged that other factors apart from God could influence variation. They also acknowledged that they could still play a role to reduce or increase variation, if they wanted to.

We realized that engaging farmers in experimentation challenged their local knowledge framework – in which plant variation expresses divine will. Though this challenge might have been detrimental to our joint learning process it was not. The reason appears to be that the experimental approach to knowledge changes knowledge practically rather than discursively. Facts were absorbed through doing farming, rather than talking about it.

For the farmers, the knowledge and understanding they gained about intra-varietal variation was seen as important and useful in maintaining seed and grain quality. Of all the plant characteristics for which variation was reported a majority of farmers indicated that seed colour was the most important to them. They pointed out that grain for food was still acceptable even if there were variations in colour. However, if the grain was for the market then it would fetch lower prices. After studying the phenomenon of single-panicle descent, they were of the opinion that variation would increase after each generation unless selection is introduced as a deliberate management strategy. Thus to maintain a uniform colour they would have to pay closer attention to selection.

Conclusions

The study set out to build upon farmers' existing knowledge on variation in order to enhance their skills in managing variation in sorghum. The results suggest that farmers have gained knowledge – better knowledge of plants and knowledge of experimentation. The knowledge farmers have gained and their ability to link the extent of the variation observed in their plants to their selection practices, could lead to more efficient ways of managing their crops and maintaining desired traits in their varieties.

For researchers, the study has revealed that local perceptions of diversity are related to local thinking about social relationships. Not only that, the strong agreement between the descriptors used by farmers and scientists (plant breeders), and the similarity between farmers' system of classification and that used by taxonomists, confirm that there is a good opportunity for convergence between scientific and local knowledge on variation. More importantly, this convergence in knowledge becomes more apparent when, as a theory of practice, farmers take part in experimentation.

The approach used in this study shows that the practice of experimentation is an important potential ally of participatory approaches to agro-technological transformation as attempted in Farmer Field School (FFS) and Participatory Technology Development (Thijssen, 2003). Through systematic experimentation involving farmers and using a science-based approach, it is possible both to help breeders generate a deeper understanding of farmers' concepts, and provide farmers with conceptual tools useful in adapting science-based strategies for crop management to meet their own needs.

This study does not claim to have altered farmers' practices over the longer run. It is as yet too early to make any such claim. What we do claim to show is that farmers can enter into experimentation modelled along scientific lines and arrive at correct inferences, low levels of formal education notwithstanding.

Participation in the rituals of experimentation, we argue, yields not only new knowledge of practical utility but also strengthens social solidarities around a shared interest in technology. Although evidence-based experimentation may challenge local normative frameworks, it does so through practice rather than discursively. This provides an effective basis for pondering and adjusting to new truths, while providing farmers with a platform to engage with scientists in a convergent debate about how to enhance co-operative and participatory approaches to rural food security.

CHAPTER 6

Evaluating local sorghum and millet seed storage practices of farmers in north-east Ghana: Learning from conducting research with farmers

Introduction

Seed is an essential production factor in crop production and yield is strongly influenced by seed quality. Musa (1999) noted that while a crop cannot perform better than the genetic potential of the variety, other aspects of quality such as seed germination potential and vigour can be subject to improvement and are a function of seed crop harvesting, seed conditioning, processing and storage. The conditions of seed production and storage are therefore crucial (Agrawal, 1986).

Farmers consider two aspects of seed to be vital: availability and quality (Almekinders & Louwaars, 1999). Availability depends on the seed systems implemented. In the informal or local seed system the farming community manages variety selection, seed production and storage under local conditions (Almekinders *et al.*, 1994). In formal seed systems, however, seed supply is a chain of activities, extending from breeding to marketing and distribution, managed by organizations (Louwaars, 1996). Seed availability is an important issue because seed supply is often disrupted by both abiotic factors (drought, flood, etc.) and biotic factors (pests, diseases, weeds, etc.). The effect of these factors on the informal sector is more pronounced than on its formal counterpart, where there is always a steady infusion of funds and technology to contain untoward effects. According to Larinde (1997), risk factors identified with on-farm seed production include drought, hygiene of planting materials, lack of credit support, infrastructure and quality of seed. These invariably influence seed availability.

Seed quality encompasses many aspects, including genetic quality (extent to which the seed lot is genetically proper, pure and true-to-type), physiological quality (ability of the seed to produce a vigorous seedling within a reasonable period), sanitary quality (the health of the seed and the resulting seedling) and physical quality (physical purity, extent of damage, seed size and seed weight). Seeds should not only germinate at the right time but should also be able to produce a vigorous seedling under environmental conditions prevailing after sowing.

Seed quality is especially critical for small-scale farmers in low-input agriculture. These farmers generally produce and store their own seed under often stressful conditions. The quality therefore may be lower and/or more variable than the quality of seed produced in formal seed systems. Weltzien & Von Brocke (2000) analysed seed systems from the perspective of farmers and noted that seed storage facilities and their effectiveness play a key role in obtaining the best quality. McGuire (2005), discussing farmer seed systems for sorghum in Ethiopia, noted that there appears to be little study of the different local storage practices or treatments used by farmers. He further suggested that there may be value in encouraging farmers to compare such practices or treatments and to share information. Wright & Tyler (1994) indicated that farmer seed management has been a neglected area in the past. In Ghana the major focus of field surveys of farmer seed, farmer seed management practices, and seed quality has been on crops such as maize and cowpea (Dankyi & Dakurah, 1993; Tripp *et al.*, 1987; Wright *et al.*, 1995). While some surveys have reported the quality of farmer-saved seed to be generally good, others have reported that a considerable proportion fell below the accepted germination standard. Walker & Tripp (1997) showed that in Ghana, the extension service did not appear to have a seed storage 'message' for farmers and there was little chance of useful interaction on seed storage issues because the period after harvest is often used by extension workers for leave or in-service training. Walker & Tripp (1997) further indicated that there was a need to develop strategies for improving farmer seed management and for increasing interaction between farmers and extensionists on seed storage issues.

The diagnostic study assessing farmers' production constraints in the use and management of sorghum diversity in Bawku East district (Ghana) revealed that storage pests were an important production constraint for the farmers in Tesnatinga and Terago villages (Kudadjie *et al.*, 2004). Infestation with weevils and termites significantly reduced sorghum and millet seed quantity and quality in storage. This often compelled affected farmers to beg for seeds from their friends, to buy from the market, or to provide labour in exchange for seed at the beginning of the farming season.

In Bawku East, farmers used a variety of different storage methods and treatments for their millet and sorghum seeds in order to maintain quality. Farmers' concept of quality was mainly related to levels of germination and seedling vigour, i.e., the physiological and sanitary seed quality. Their main aim in storing and protecting their seed was to obtain healthy seeds that would germinate when sown. Farmers in the study were of the view that seeds need better care than grain for consumption and therefore should be stored and treated differently.

Discussions with farmers revealed that currently farmers only used one storage method or seed treatment at a time. Some farmers indicated that they had switched to treating their millet seeds with chemicals to upgrade the sanitary quality following the observation that germination was low in seed lots treated with wood ash. On the other hand, other farmers did not treat their seeds at all, not finding the need to change because they had experienced no problems. This generated two questions among farmers which we used (experimentally) as the basis for generating further interaction:

- were all these storage and treatment methods truly effective?
- were some methods more effective than others?

No farmer had tried or compared all storage methods, for either sorghum or millet seed. Moreover, in these communities seed storage is not a common topic of discussion, and because storage normally takes place within the confines of the house there are very few opportunities for farmers to learn from one another. The farmers were very much interested in answering the above questions, and expressed a desire to test and compare the effectiveness of their seed storage and treatment methods on seed quality. They proposed the use of germination capacity as a test of quality and each farmer in the group offered to provide samples from his/her seed lots for the test.

The study was therefore aimed at:

- Describing sorghum and millet seed storage and treatment methods used by farmers in the study area;
- Assessing with farmers the effect of their different storage methods on the physiological quality (focusing on germination) of sorghum and millet seed;
- Drawing lessons from conducting research with farmers.

Methodology

Selection of farmers

Twenty farmers were involved in the experimentation. These were selected by the group of farmers with whom the diagnostic study was carried out, to represent farmers from the two villages. The criteria for selection were commitment and strong interest in the experiments. The farmers were quite heterogeneous and differed in age, experience, position in the community, ethnicity and gender. All farmers were illiterate. Out of the 20 farmers, 17 were men and 3 were women. With regard to age 15 were above 45 years, and the other 5 between 25 and 40 years. The poor representation of youth in the group is typical of what pertains in the region. There is a continual out-migration of landless unemployed youth from the area to southern Ghana (Cleveland, 1991; Ghana Statistical Service, 2002). Four farmers had had some contact with agricultural extension agents, but the majority had little or no previous contact, nor had they ever been involved in any kind of trials with extension agents or researchers.

Assessment of farmers' seed storage methods

After the need for conducting research had been established through interaction with farmers, visits were made to the home of each farmer who would be involved in the experimentation. During such visits in-depth discussions were held to elicit farmers' descriptions of how seeds were handled, including their treatment and storage. Storage structures and containers were shown to the researcher, examined and compared. On several occasions sorghum seeds were brought out and shown to the researchers upon request. Most farmers allowed us to see how and where millet seeds were stored but often refrained from opening the storage facilities. Group discussions were later held to confirm and clarify some of the information gathered during individual visits.

Planning of seed testing methodology

Although it had already been decided with farmers to evaluate the effectiveness of their seed storage practices using germination tests it was necessary to work out the details of how the experimentation would be done.

Standard methods for carrying out germination tests exist (ISTA, 1999) and, ideally, testing should be done in accredited seed laboratories. Van der Burg (1999) noted that for small companies or still developing seed systems it may be difficult to fully adhere to ISTA-rules, seed testing results must, however, be reproducible, even if only locally available materials and methods can be used.

It is therefore necessary to organize such tests with farmers by adapting a method to their own local conditions, to enhance their appreciation of the experiment while at the same time ensuring an adequate level of precision. This, however, required some negotiations with farmers.

Negotiations

The form of experimentation was reached through open discussions at group meetings. Farmers were encouraged to express their individual views and concerns. Suggestions were made and a general consensus was reached. The issues on which agreements were made with the farmers included the following: type of germination medium to use, number of seeds per treatment (storage practice), number of replications, number of days after which seeds would be counted, the source of seeds, and when to carry out the tests. The decisions were arrived at in the following ways.

The type of growth medium was considered important by a young farmer who was concerned about whose land would be used for the tests. For him, volunteering his land meant being deprived of land for food. Farmers did not appear very comfortable about singling out one farmer’s plot either. Another farmer pointed out that because the fertility of the land was not uniform across their fields we needed soil of the same status to avoid getting different results for each treatment. This helped to establish the fact that a uniform germination medium and uniform conditions were needed for all the tests. Since it was agreed that equal treatment should be given to all the samples the suggestion by the researcher to use plastic containers, and to fill them with sand from the same source, was readily welcomed as the best solution.

On the number of seeds per treatment, the researcher initially suggested that 100 seeds per seed lot from each storage method be used. This number was rejected by farmers because they felt it would be too many and tiresome to count. Instead, they suggested that we used 50 seeds because that seemed more reasonable to them.

The need for replicates did not require much discussion because farmers understood that using only one farmer's sample to test a particular method was not good enough to draw a valid conclusion.

According to the farmers, counting could be done after five days, because by then it would be possible to determine which seeds had germinated. To be doubly sure, however, they were of the opinion that we should wait for two more days before counting. Eventually the group settled on the eighth day, if the seventh day fell on a market day which they excluded from their meeting days.

The period when the experiment would be done was decided unanimously, as the beginning of the season, when farmers normally planted their millet and sorghum. Traditionally, one may not fetch from seeds reserved for planting to sow without performing some ritual. This ritual will only be done once by the head of the household and only at planting time. It would therefore have been impossible to carry out this test before the growing season began because no farmer would be willing to contravene this rule. This also ensured that the seeds remained in storage for the normal period that most farmers keep their seed before they were tested. All the farmers wanted their seeds to be used for the tests but that meant that we would have had too many samples to count (especially in the case of sorghum where farmers stored several different varieties), an issue already considered a problem. It was difficult to decide what criterion to use for determining whose seeds should be used. We therefore agreed to collect seeds from everyone, but randomly pick three samples per storage/treatment method.

Seed collection

Two days before the tests the researcher and assistant visited each farmer in his/her home and collected a handful of their seeds. Seeds were placed in separate envelopes and labelled. Labels for millet indicated the type of storage method and treatment used by each farmer, and for sorghum labels indicated the storage method and variety.

Experiments with millet

For millet seed the following treatments were compared:

Seeds untreated and stored in sack – None + Sack

Seeds untreated and stored in pot – None + Pot

Seeds treated with ash and stored in sack – Ash + Sack
Seeds treated with ash and stored in pot – Ash + Pot
Seeds treated with chemical and stored in sack – Chemical + Sack
Seeds treated with chemical and stored in pot – Chemical + Pot

Plastic pots of uniform size (15 cm diameter) were filled with river sand collected from one of the villages, watered and placed under a fenced shed. The following morning, the seeds were grouped according to different storage methods/ treatments. Farmers formed three groups and each group randomly picked one envelope from each storage method. Thus each storage method was replicated three times (three different farmer seed lots, but using the same storage method). From each seed lot four replicates of 50 seeds were counted and planted. Each group of farmers planted these seeds in labelled pots. The total number of experimental units was 72. The seeds were watered after the third day and on the eighth day we met and counted all the germinated seedlings.

Experiments with sorghum
The varieties of sorghum seeds used in the experiments were Naga white, Naga red, Belko and Kapaala. The following treatments were compared:
Naga red seeds stored in the room – NR + Room
Naga white seeds stored in the room – NW + Room
Naga red seeds stored in the mud silo – NR + Mud silo
Naga red seeds stored in the grass barn - NR + Grass barn
Naga red seeds under smoke storage – NR + Smoke
Belko seeds stored in the room – B + Room
Belko seeds stored in the mud silo – B + Mud silo
Belko seeds stored in the grass barn – B + Grass barn
Kapaala seeds stored in the mud silo – K + Mud silo
Kapaala seeds stored in the grass barn – K + Grass barn

Pot filling was done as in the case of the millet experiment. However, in the case of sorghum the number of samples used was different. Two to three samples per storage place × variety combination were used. Very few farmers had Naga white and Kapaala seeds in storage. Therefore, instead of using three different samples as in the case of millet only two samples each were obtained. Most farmers did not store their seeds in the kitchen smoke and only two samples of Naga red were obtained. Therefore, instead of using three different seed lots, as in the case of millet, for some varieties only two seed lots were used. The design was unbalanced, therefore. The number of replications was four. The total number of experimental units was 80. The seeds were watered after the third day and on the eighth day we met and counted all the germinated seedlings.

Recording and analysis

The results were recorded on large sheets of cardboard by the farmers themselves. They together developed their own symbols and pictograms to represent the seed treatment and storage methods, to aid their own understanding. Each farmer counted the total number of germinated seedlings and recorded them in columns drawn on a sheet. A long stroke of the marker pen represented ten germinated seedlings and a shorter one represented a single germinated seedling. This process was very slow initially, but progressed steadily once members of the group got the hang of it.

The compilation was done by the researcher as follows: for each seed lot (four replicates of 50 seeds) the number of germinated seeds was counted and the percentage calculated. This percentage was averaged over the number of seed lots under one treatment/storage method. The mean germination percentages obtained for each method were then used to plot histograms using the farmers' symbols on large diagrams. These were then taken to farmers during the next meeting so that they could inspect the data, make their own analysis, and arrive at their own conclusions.

Analysis of variance was also performed on the results. The proportion of seed lots with germination greater than or equal to the minimum national germination standard for certified seed (75%) was also analysed. This was done by counting the number of seed lots from each treatment/storage method whose germination exceeded the minimum standard, and expressing it as a percentage of the whole. When the tests were concluded a meeting with stakeholders from the Ministry of Agriculture, a research institute (SARI), farmers involved in the research and a representative of the group of traders selling agro-chemicals was organized. At this meeting farmers made a presentation of the experimental procedure and showed how they analysed the results.

Results and discussion

Seed storage methods

Farmers store their seeds for the next planting season after the harvest. The storage period normally extends from September/October to May for millet and from November to May/June for sorghum, depending on when the rains begin.

Storage of millet

Panicles selected for seed are threshed and winnowed after they are considered sufficiently dried by farmers. Seeds may be stored in either of two kinds of containers:

clay pots with tight fitting lids or polypropylene sacks (fertilizer bags). Many of these sacks have an inner lining of polythene. Before storage the seeds may be treated with white wood ash obtained from the kitchen fires, or with chemical insecticides bought from the local market. The insecticides are found in powder form and often contain the active ingredient Cypermethrin. These are thoroughly mixed with the seeds before tying the sacks or sealing up the pots. When pots are used a layer of ash or insecticide is usually applied to the seeds before covering with the lid. To keep the pots air tight the lids are sealed with cow dung. Ash may also be sprinkled on the seeds in the sack to form a layer before the sack is tied.

Seeds stored in sacks are always kept in rooms and not in the open. The sacks may be placed on a slightly raised platform above the ground away from moisture, crawling insects, or anything that might perforate them. Pots may be stored in the open air within the compound throughout the long dry season. Some households keep the pots containing seeds in rooms in the custody of the eldest wife of the household head until the planting season.

Storage of sorghum

Sorghum seed is usually stored on the panicle but in some cases the panicles may be threshed and the seeds stored in polypropylene sacks. Several panicles are tied together and suspended at the peduncle from the roofs of storage barns. These barns ('mud silos') are circular in shape and made of mud or earth. They are usually cool and said to be durable but not very airy. A portion of the thatch roof is raised during the day for aeration. The barns may be constructed on stones or built directly attached to the ground. Other barns are made of grass ('grass barns') but reinforced with wooden stakes that are raised above the ground. The space between the base and the ground provides protection and shade for fowls. The sides of the grass barns may be protected with old aluminium sheets and thick thorns to ward off pigs and cattle. Grass barns are very airy but less durable than the mud silos. They are also very susceptible to fire and termite attack. Storage barns are located outside and in front of the compounds.

Seeds may also be hung from the roofs of rooms within the compound. These rooms are also built of earth but may be roofed with aluminium sheets or thatch. Some farmers also hang the panicles from roofs in the kitchen or on trees in the open air. Storage of sorghum seed or grain is mainly the preserve of men, and women are not allowed to store sorghum seed except in cases where a woman is the household head.

Millet seed quality

The mean germination percentages of farmers' millet seed samples from the two study villages are presented in Table 1. The overall mean germination was 83% with a range of 78% to 87%. The seed treatment with the lowest mean germination (78%) was ash while the highest germination (87%) was obtained from seeds treated with chemicals. However, no significant difference in germination was observed between the three treatments. This contrasts with findings by Bishaw (2004) from Syria, where germination was significantly better for chemically treated wheat seeds than for untreated seeds.

Before our experiment some farmers had mentioned that they had changed from using ash to chemical treatment when they failed to obtain the desired quality of seeds with regard to germination. The use of ash is, however, a common practice used by farmers in several countries for storing beans and cowpea (Almekinders *et al.*, 1994, Wright & Tyler 1994). Ash is reported to reduce damage by bruchids and other insects by damaging their cuticle and causing them to dehydrate (Almekinders & Louwaars, 1999).

The mean germination of seeds stored in sacks was slightly higher (84%) than for seeds stored in pots (82%). No significant difference in germination was observed between the two storage methods. There was no significant interaction between the treatment and storage method. The results show that the physiological quality of seeds stored in pots was comparable to seeds stored in sacks. It is, however, known that the storage environment influences the quality of seeds, especially germination, if the seed is predisposed to high moisture, high temperature, or infestation with storage pests (Basra, 1995; Wilson, 1995).

Bishaw (2004) found that wheat seed samples collected from farmers in Ethiopia maintained higher standards of germination compared to seeds from Syria. He attributed this difference to differences in storage facilities. Farmers from Ethiopia used storage bins made of interwoven bamboo sticks internally plastered with clay and cereal straw while Syrian farmers stored their seeds in polypropylene sacks. He further noted that seeds kept in polypropylene sacks are generally vulnerable to pest attack and changes in moisture content relative to the ambient temperature and relative humidity. These all have a detrimental effect on the physiological quality of the seed. In the present case, however, humidity and moisture may not be important factors since the district lies in a zone where relative humidity rarely exceeds 37% during the storage period.

Sorghum seed quality

Table 2 shows the mean germination percentage of different sorghum varieties for the storage methods tested. The mean germination percentages ranged from 62% to 84%. The Belko variety showed relatively high germination percentages under room, mud

Table 1. Physiological quality (as reflected by germination percentage) of millet seed from different storage methods used by farmers in Bawku East district.

Storage method and treatment	Mean germination (%)
Seeds untreated and stored in sack (None + Sack)	86
Seeds untreated and stored in pot (None + Pot)	80
Seeds treated with ash and stored in sack (Ash + Sack)	82
Seeds treated with ash and stored in pot (Ash + Pot)	78
Seeds treated with chemical and stored in sack (Chemical + Sack)	84
Seeds treated with chemical and stored in pot (Chemical + Pot)	87
Mean None	83
Mean Ash	80
Mean Chemical	86
Probability treatment effect	0.311
Mean Sack	84
Mean Pot	82
Probability storage effect	0.345
Probability interaction (storage* treatment)	0.367
Overall mean	83

silo, and grass barn storage. The other varieties showed relatively lower germination (on average <74%). The difference may be attributed to the differences in the time of harvesting and drying. Whereas Belko is harvested in the dry season, the other varieties mature during the rains when drying is difficult. Almekinders & Louwaars (1999) pointed out that varieties may differ very much in their adaptation to different environmental conditions and may require different seed management practices. Naga red, however, showed a high germination (84%) under smoke storage – much higher than in the other storage places. It is possible that because Naga red seeds are soft and more susceptible to insect damage, hanging the seeds in the smoke may help to keep them dry and also reduce the insect and disease damage that might otherwise reduce the seed quality. Surprisingly, however, only two farmers within the group used the smoke method of storage.

There was a significant difference ($p<0.05$) in germination between varieties but not between storage methods. Wright *et al.* (1995) also found that the crop variety, among other factors, had significant effects on the germination of beans, maize, cowpea, groundnuts and soybean in Ghana, Malawi, and Tanzania. The interaction between

Table 2. Physiological quality (as reflected by germination percentage) of sorghum seed by variety and storage method used by farmers in Bawku East district. n = number of seed lots (total n = 22).

Storage method	Mean germination (%) Variety of seed lots				Mean
	Naga white (n = 2)	Naga red (n = 10)	Belko (n = 7)	Kapaala (n = 3)	
Room	73	73	82	-	75
Mud silo	-	62	84	72	74
Grass barn	-	69	82	67	74
Smoke	-	84	-	-	84
Mean	73	71	83	70	
Probability storage effect	0.188				
Probability variety effect	0.037				
Probability interaction (storage×variety)	0.698				

variety and storage method did not show any significant effect on the germination capacity, but this was probably the result of an unbalanced experimental design. For Naga red, for example, a wide range of germination percentages was present (62%–84%), whereas for Belko the range was only 82%–84%.

Farmers' presentation, understanding and analysis of the results of the experiments

Germination tests on millet seed

Prior to joint discussion or analysis of the results with the farmers they were given the opportunity to comment freely on the outcome of the both experiments. Their comments are presented here without alterations. Box 1 reports the comments on millet from farmers during a group discussion. Box 2 reports the comments of individual farmers during follow-up visits, after group discussions. The comments are not presented in any particular order. Farmers did not make much reference to the storage method, possibly because it was not important to them. Instead they were more concerned about the different treatments used. The discussion showed that they were more interested in the treatment which gave the best germination. After determining the best treatment they examined the treatment identified and explained why it might not necessarily be the best option for every farmer. All the seed treatments were considered effective and to serve their own purpose, depending on the situation. While some considered the best seed treatment to be the one that gave the highest germination, others went further, drawing attention to the difference between the best and next best. Factors such as cost, time, ability and health risk were considered very important for deciding on which seed treatment to use.

Box 1: Farmers' comments on millet seed germination

Haruna: The seeds treated with chemical in the pot were the best because this treatment had the highest number of seeds germinated.
Issaka: Since the chemical-treated seed lot had the highest number of germinated seeds it is the best.
Ayariga: The chemical/pot treated seeds are the best.
Akunye: The non-treated seed in the sack method is the best because you do not spend money on buying any chemical yet the germination is almost as good as the chemical pot treated one.
Alale: If we vote on any issue, which ever has the highest is the winner, therefore it should be the chemical-treated seeds in the pot.
Adam: Whichever treatment has better germination is the best.
Karim: The non-treated seeds were almost as good as the chemical-treated ones but that depends on the hands of the person storing the seed. Not all hands are the same.
Haruna: It is the overall effect that we are seeing; if we had three farmers' seed lots for one type of storage and one seed lot did not germinate well, the other two seed lots with high germination will still give it a good germination.
Adobo: We have never stored seeds in chemical in the past but use ash and in the pot. With this method, whatever seeds are left over can be used for *zom kom* (flour water). But now the chemical is killing people gradually as well as animals. So in my opinion the non-treated is the best.
Karim: Let's get the facts right. Eating seeds treated with a chemical does not kill humans or fowls. That was a case of deliberate poisoning that occurred and it was DDT!
Mahadi: The ash treated seeds in the sack are better than the ash treated in the pot.
Researcher: The differences in the numbers don't appear to be very large. Are the methods really different in their effect? Do you maintain your earlier stand that there are no differences between the different methods?
Azangbego: Since all had seeds which germinated it is okay to use any method.
Adobo: The non-treatment method is the best because the person did not spend money on chemical and yet had good germination.
Haruna: If you do not have money then the non-treated seed in pot is very good.
Ayariga & Azangbego: Whether you used chemical or not if the crop is not put in the soil how will one know?

Box 2: Farmers' views on the best method of storage/treatment for millet seed

Mahadi: I remember that the non-treated seeds in the sack were almost as good as the chemical treated seeds. But to me the choice of which method to use depends on one's ability. If your hands are not good then it will be better for you to use chemicals otherwise your seeds will spoil. Others can store seeds up to 2–3 years and still they will stay good and germinate.
Adam: I don't use ash or chemical. Since I was a child we didn't know about chemicals or even thought about ash, just make sure your seeds are winnowed well after threshing to remove the glumes, make sure the seeds are clean before you store them in the pot, cover and seal tightly and that's it!
Azangbego: Seeds treated with the chemical germinated more than the other seeds so in that sense that is the best. But the differences are not much and if someone had to buy the chemical then you see that it is not really worth it. I can keep my seeds without treating it in any way and I will continue that way. All the methods used are good but there are still some differences. The best method is the non-treatment but I was surprised that everyone saw the chemical treated to be the best!
Ayaug: The chemical treated seeds had better germination than the others so I think that method is better than the others.
Researcher: But the differences were not so large?
Ayaug: It is not only because of the counting of the germinated seeds that I say so but when you plant it in the field some of the conditions in the soil does not allow the seed to germinate, but when you treat the seed it is better. Some people can use all the chemicals and yet their seeds will spoil, others will not and it will be okay. That depends on the person's hand. Again, some may start with good seeds but during the period of storage they will open the container and fetch some seeds, in this case some weevils can enter them and by planting time the seeds will be spoilt.
Mariama: The chemical treated seeds germinated more than the other two, so it is the best. To me even a difference of two can mean something, it means two extra plants, even though the non-treated seed is almost as good. But I prefer the ash, that is what I know how to use.
Akunye: The difference between the non-treated seeds and the other seeds is small. The non-treated seeds are better than the ash-treated and those are also better than the chemical-treated seeds. It is risky to use the chemical because your family may have to feed on it when you become hard up. The money used to buy the chemical could be used for something else.
Apoasana: With regard to the germination, I think both the non-treated and ash-treated seeds performed very well. No chemical was applied to those two and yet their germination was almost as good as the chemical treated seeds.
Dasmani: All the three were good because for each pot almost 40 or more seeds out of the 50 germinated. You can't get all your seeds germinating when you plant. The ground too has something that will take some and that is why we put in enough to get some. We told you also about the centipedes and millipedes that destroy some seeds. Those who mix their seeds with chemicals before planting are able to offset it. The non-treatment is better, but it depends on the hand. If someone has bad hands the chemical is his option, but if his hands are good then he does not need the chemical. If you dry your seeds well and tie them well in the sack, making sure no one opens it till time of planting it will keep well. But if you don't everything will turn into flour.

Most farmers generally agreed that the chemical treatment of seeds gave the best results but did not rank it above the non-treated seeds. A poor widow farmer, however, insisted that even one extra germinated seed was significant. Despite this acknowledgement, it was obvious that it would not change her normal practice of using ash, which gave less germination than the chemical.

For three farmers, Azangbengo, Akunye and Apoasana (Box 2), there was no reason why a farmer should bother to treat his seeds with ash or chemicals if almost the same results could be obtained from non-treated seeds. However, other farmers remarked that although the non-treated seeds were better, it was the preserve of the few farmers whose "hands are good". If one did not have this ability then ash or chemical became the obvious choice.

From the point of view of economics, the difference in germination between the best (86%) and worst (80%) treatment is 6%. On the average one bowl of seed/grain costs about 9000 cedis (US$ 0.82). This means that if a farmer wanted to set aside that much extra seed and not treat the seed, it would cost him about 560 cedis per bowl which is about half what he would spend to treat the seed at 1000 cedis per satchet per bowl.

Thus for those who do not use the chemical, there are drawbacks, but for users it has advantages over the other methods. According to some farmers the sellers assure them that the chemical is not harmful to humans but only to insects, and that its potency reduces after 2–3 months. More importantly, seeds treated with the chemical were protected from soil pests which could attack the seeds after sowing. But non-users think that it is not safe to use the chemical to treat their seeds because many farmers store a lot more seeds than they intend to use for planting and the leftover is normally milled for *zom* (flour) or *zomkom* (flour water). This is a quick snack taken when food is not readily available. Traditionally, some of the seed is used to prepare flour water for pouring libation to the ancestors and then the rest is consumed by the sowing party before sowing begins. So, apart from the possible harm from the chemical, it was pointed out that it gave an undesirable and 'salty' taste to the *zom* or *zomkom*. Users of the chemical contend, however, that once such seeds are winnowed all the dust from the chemical blows off leaving no residues. The seed can then be eaten without problems.

There appeared to be two schools of thought with regard to the subject of 'good hands' within the farming community. It is believed that some people are gifted with the ability to store seeds without loss in quality and without the use of any additives. Others might take every precaution and yet find their seeds have deteriorated when it is time to sow. This cannot be explained, they say, and it is only *Winam* (God) who understands. There are others who think that good hands are simply a matter of good seed storage practices, such as ensuring proper drying and aeration of seeds before storage, prevention of moisture during storage, and keeping seeds airtight and free from insect pests. If these are all ensured then one will always have good seed. It was realized upon further probing that farmers from the group who did not use any form of treatment for their seed took other measures to ensure that their seeds kept well. During the period of storage, seeds were occasionally sun-dried for a few hours, aired and winnowed, and put back into air-tight containers. This practice was meant to kill any hidden insects pests which may have entered the seeds or were present at the time of storage. Since the presence of ash or insecticide may also act as a protectant it may explain why the results from the germination tests were almost comparable for the different treatments. Without downplaying the view of some farmers that keeping good seeds is beyond the reach of some, it is also important to encourage the use of helpful storage practices adopted by the 'non-treatment' users. This could serve as local knowledge to be further developed, built upon to become a body of knowledge, useful across a range of agricultural communities in the region.

Tests on sorghum

In their discussion and analysis of sorghum seed germination farmers compared the variety with the highest germination with other varieties. They went on further to try and explain the results, linking them to their own experience and knowledge of the varieties. They did not pay much attention to the unbalanced nature of the design; it was later pointed out to them.

Some farmers ascribed the lower germination percentage observed for Kapaala and Naga red to the endosperm texture and time of harvesting. Kapaala matures during the rainy season, and this makes drying a problem. The mature grains easily germinate on the stalk once they are wet. When such seeds are stored many go mouldy and do not germinate when sown. This assertion by farmers is corroborated by Woldeselassie (1999) who noted that the extended rainfall during crop maturity and at harvest time contributed to the loss of physiological quality of barley seed because of pre-harvest sprouting. Naga red grains are soft and farmers who use the grain for food usually harvest it as soon as it matures, before it dries completely. This is because the food quality is best at that stage and deteriorates with decreasing moisture content. However, for seed the moisture content must be lower than that for grain. Rather than leave some panicles intended for seed in the field to attain full dryness farmers tend to harvest the whole field. Seeds from such early harvested stock are not adequately dried and will not germinate because they are not sufficiently dried or mature. It was then proposed by a farmer that hanging in smoke may be the best way to store Naga red since the results show that its germination was good and comparable to that of Belko.

Attention was drawn, however, to the fact that, for that particular storage method, one seed lot fewer than the required number was used because we could not find many farmers using that storage method, from whom to take a sample. This finding is not very conclusive.

Farmers also suggested that the reason why Belko had a better germination under all storage conditions was because it always matures when the rains are over. Drying,

Box 3. Farmers' views on sorghum seed germination

Adam & Seidu: Out of all the seeds stored in the Napaug (grass barn), Belko did better than the Naga red and Kapaala but Naga red was also better than Kapaala.
Haruna: For the Mud silo, Belko is better, followed by Kapaala and Naga red.
Seidu: the Belko seeds that were threshed and stored in the sack treatment also had more seeds germinated than the Kapaala seeds and the difference is just one, but Naga red is much lower.
Researcher: So what do you think? Is the difference of one important?
Seidu: Yes, it means that if you plant two seeds of each, Belko is likely to give you one plant but the other two will give none. Even one plant can give you a big panicle from which you can get many seeds, so yes a difference of one is important.
Mamudu: Yes, a difference of one still matters, even when you vote the one who wins is the one who has more. But as a farmer even one makes a difference because it means more food.
Haruna: Well, I disagree because at the end of the day even if many germinate you will still thin out to leave two in a hole so the difference of one is not that important.
Adam: For all the storage methods I notice that Naga red germination is lower than the germination of the other varieties.
Akunye: It means that the storage system should be changed.
Researcher: If the problem is with the storage method then why is it that it is low for all the three storage methods tested?
Agurie: It may be due to the way the seeds were selected. If they were not well dried or well matured before they were selected then the seeds could go bad during storage.
Seidu ayaug: In our fathers' time they allowed Naga red to be well matured and dry before they were selected but now they are harvested early and are not allowed to dry well.
Issaka: The Naga red seeds are not even hard but that of Belko and Kapaala are much harder so they can keep better.
Red: I disagree with you, the seeds of Naga white are also not as hard but from the results Naga white germination is still better than Naga red stored in the grass barn, mud silo, or in the threshed form.
Akunye: But Naga red stored in the smoke also gave a high germination comparable to that for Belko.

therefore, occurs during the dry season. Moreover its grains are hard and resistant to insect pests. Thus farmers attributed the difference in germination percentage to the variety, grain hardness, and seed care before storage, as well as the time and stage of harvesting.

Knowledge sharing and learning

This seed germination experiment provided the opportunity for different farmers from two different communities to form a common platform to discuss and learn about seed storage, a household topic which is not often openly discussed.

Each stage of the experiment – planning, implementation, results and analysis – presented different opportunities for learning and contributed to building knowledge. At the beginning the discussions on different storage systems and the practices used by farmers was itself very illuminating for some farmers who were unaware of how other farmers kept and stored their seed. Several farmers indicated surprise at the fact that some continued to use ash to protect their millet seeds. This, for some, generated curiosity and motivated them to find out for themselves how effective such storage practices really were. To use one farmer's words, "we are finding out other methods that people use to store their seeds. If in the past someone used a treatment without much success this experiment gives him another alternative to try."

For another farmer it was not only the outcome of the experimentation but the method which provided the learning. To him it was a way of determining the germination capacity of his seeds before planting if he was not sure of the quality. This was knowledge that he found applicable to his farming in general. For others, additional knowledge was gained which they hoped to pass on to others. Others had formed their own opinions as to what storage methods were best under what situations and could now advise others. According to one farmer, "we have now learnt our lesson, those who say the chemical is the best will think otherwise, because others are also good. If you want to cut down on your cost then you should advise yourself and try the other methods".

From the above it may be inferred that the knowledge gained by farmers served different purposes; some was for their own use, or to satisfy curiosity, other items were for passing on to others.

The learning outcomes were not restricted to farmers alone but also applied to extension staff and other researchers who became involved in the study at implementation stage. Farmers had the opportunity to present their findings and express their opinions on the outcome at an inter-institutional meeting. Other researchers and scientists, staff of the Ministry of Agriculture and other farmers, realized the capability of farmers to be involved in experimentation, to make meaningful analysis, and draw correct inferences from results and that they could, therefore, if given the opportunity, contribute more to research, and thus widen its scope and effectiveness. Although efforts have been made in the past to involve farmers in research we may suspect that the extent to which their involvement has been encouraged is limited. Here, we have demonstrated the value of actually organizing simple experiments with farmers, both as a way of stimulating local curiosity, and of suggesting specific ways in which farmers and researchers could engage.

Farmers' concept of scientific experimentation

In conducting experiments with farmers the methods and/or protocol used may not always be consistent with farmers' expectation. Understanding the normal practice of farmers, of drawing sustained comparison between their way of arriving at evaluative decisions, and understanding how scientists develop experimental decision-making, could help farmers and researchers arrive at procedures that are acceptable to all. In science replication improves precision, provides an estimate of experimental error, and is also a means of increasing the scope of inference from an experiment. In a seed quality test such as the one presented in this study, the protocol requires that four replicates of 100 seeds are used for the tests (ISTA, 1999). Farmers did not see any justification for using four replications from the same seed lot and considered replication a waste of time. In short, they appeared to have difficulty in understanding the need to examine variance. However, drawing a parallel between replication and what farmers practise when sowing helped to press the point home to them. Although they would eventually need two plants per hill, they often put several seeds in a hole when sowing. This is done as a form of security against the following; unforeseen errors, variability inherent in the seeds, or differences in soil, light or other factors that the seed may be subject to. In other words, farmers do have a working notion of variance; the task is to bring it out from the local cultural or practical context, and then to explain the protocol for the experiment in this light. This is similar to the argument made by human rights researchers that rights-based development needs to proceed not on the basis of abstract declarations but through locating the local, culturally-embedded notion equivalent to declared principle (Archibald & Richards, 2002). This has been termed the 'inductive' approach to human rights.

An understanding of the cultural setting of our farmers provides insight into how the results of experimentation may be interpreted or accepted. At the end of the experimentation process farmers were asked whether the results would influence their decisions about what storage system to use or whether they would change their seeding rate. Even though many farmers had talked about the knowledge gained through these tests it became apparent that to change ones' practice based on one observation was considered a hasty judgement by the majority. Farmers were of the opinion that they would need to repeat the experiment before they could make a decision. They explained that one could not judge based on one result only nor should one make an interpretation from a single event. The analogy was drawn with their own practice of storing millet. Old women are allowed to keep and store millet seed for the household. The household head who so wishes may give his seeds to any such woman to keep. However, if at the beginning of the growing season it is found that the seeds have gone bad the tendency is to blame the woman (she lacks 'good hands' and perhaps lurking behind any such judgement there would be a complex of ideas concerning the loyalties of women, divided between the husband's house and her own lineage).

This surfaced as an issue in one discussion with the group. It was suggested that the woman would be given another chance to store seed, but that if the same result was obtained then another woman would be asked to keep the seed or the man might decide to keep it himself. There was some discussion of whether one or two failures would be enough to test fairly a woman's competence. This discussion shows farmers in the process of edging towards forming a scientific concept of variance and confidence limits. Their way of reasoning, in the end, is not very different from scientific decision making. Scientific field experiments are usually repeated over a period of years or in different locations or by different people before secure recommendations can be made. A problem for farmers, however, is that 'experimental events' often carry grave consequences – few farmers would be able to risk more than one or two 'failures' in seed management. Real life pressures push them to forming snap judgements in regard to auspicious or inauspicious occurrences. But the potential to form scientific judgements – on the evidence so far discussed – seems general among the group of farmers with whom the work was conducted.

Implications for methodology and approach in conducting research with farmers

At the beginning of our research, contributions to discussions and sharing of ideas during group meetings were dominated mainly by the elderly males or farmers with more resources. A greater effort was needed to draw out the women and the younger farmers who tended to agree with everything the older ones said. Asking for the opinion of the younger ones in the presence of the older farmers helped, but did not always work. Within Kusasi culture much respect is given to the elderly, who are believed to know better, and disagreement with the elderly is usually frowned on. Therefore, effort was made to spend more time with each farmer on an individual basis in order to get a wider opinion on issues. Such 'solicited' views were then later introduced into the wider group discussions.

By encouraging farmers to participate in designing the experiment it was expected that they would develop a sense of ownership of the results and find the results more acceptable. Knowledge sharing was contingent upon the active involvement of farmer-experimenters. It was soon obvious, however, that asking old farmers to count a hundred seeds eighty times in the name of participation was asking for too much! But negotiation was necessary to agree on terms that would reduce drudgery for the experimenters without compromising the method.

Engaging farmers successfully in research demands that we value their experience and recognize their knowledge. In order to do this effectively everybody's skill and knowledge must be appreciated or acknowledged. This may be either at the group or individual level.

The major findings from the study came through farmers' own analysis and recommendations, backed by their local knowledge and experience. The notion that the 'educated' know it all had to be de-emphasized when working with them. This suggests a need to overcome the urge to provide ready answers at the slightest opportunity. That was sometimes difficult to do, because some farmers expected that answers to their questions/problems should come from outside themselves. But we tried to encourage them to be analytical by asking stimulating questions and facilitating analytic discussions. Researcher interventions of this sort have been deliberately included in the record of discussions and comments in Boxes 1, 2 and 3 to emphasize this point.

Conclusions

The seed germination tests revealed some variation in the quality of millet seeds when using different storage method/practices. However these differences were not large, nor were they statistically significant. Furthermore the study showed that the quality of millet seed saved and used by farmers is generally high with regard to germination. Ndjeuna (2002) has similarly reported a high average germination (88%) for millet seed samples collected from farmers in Niger. Farmers generally have been found to use high seed rates because it is assumed they are unsure of the germination capacity of their seed. One may argue that millet and sorghum are undemanding in terms of the input-output ratio of planting material to harvested output; however, the knowledge provided through these tests is still considered valuable for farmers who think that even one germinated seed more or less is important.

The germination tests conducted on sorghum seed showed significant differences between varieties. The seed quality for the long-cycle variety (Belko) was better under all storage methods than for the short-cycle varieties (Naga white, Naga red and Kapaala). However, one may not attribute this difference to the cycle length only but to the different environmental conditions under which seeds of the long-cycle and short-cycle varieties are harvested, selected and produced. It is suggested that farmers pay particular attention to the period of harvesting, selection, handling and drying, especially for seeds of the early varieties that mature during the rainy season. Understanding the grain characteristics of the different varieties may also be helpful for farmers in their seed management practices. For Naga red sorghum the smoke method of storage may be a better alternative to the mud silo or grass barn.

In conducting research with farmers, knowing and understanding the culture of the people is important for achieving cooperation. Areas of tension which could build up may be reduced or avoided if culturally accepted ways of introducing scientific information to farmers are known and used. Working with a heterogeneous group of farmers demands much investment in terms of time and energy but the benefits are richer and more diverse in terms of knowledge and experience. Even though these tests may be considered as simple and therefore easy for farmers to understand, it still shows that farmers are able to make meaningful analysis and that they can contribute meaningfully to scientific experimentation. Whether the research is complex or simple the challenge lies in helping farmers to understand what is done and why, and to have their maximum contribution to the research.

It is also important to stimulate self-analysis of village problems, in the hope of triggering endogenous change processes. The present material has shown that introducing an experimental methodology to Ghanaian farmers, where the problem is important to them, results in a good response, including discussion among farmers, and between farmers and researchers, about the possibilities of evidence-driven decision making in areas of local problem solving. It is a significant real challenge for further work to make this a self-sustaining process at village level.

CHAPTER 7

Efforts at commercializing sorghum production in Ghana: The case of an out-grower contract farming scheme in Garu-Tempane

Introduction

Contract farming, understood as a collection of institutional and production relations, has been viewed as a crucial means through which agriculture becomes industrialized. It is regarded as a strategy for agricultural transformation in developing countries because it has the potential to solve problems with marketing agricultural produce (Little & Watts, 1994). It is also considered a tool for achieving growth through 'free' market principles and private sector involvement (Glover, 1984). There are several definitions in current use (Eaton & Sheperd, 2001; Glover, 1984; Little & Watts, 1994; Mighell & Jones; 1963; Roy, 1972). Variants of contract farming arrangements are investigated. However, usually the institution takes the form of a central processing or exporting unit which purchases the harvests of farmers/growers. The terms of the purchase are arranged through contracts that vary from case to case; the grower provides land, labour and tools while the purchasing unit provides input credit and technical advice (Glover, 1994; Grosh, 1994; Kirsten & Sartorious, 2002). The contract could also specify the price, quantity and quality of produce, the conditions of production, and the delivery and grading requirements (Runsten & Key, 1996; Sporleder, 1992).

As an institution in agriculture, contract farming has a long history, dating back to the 19th century and early part of the 20th century in the United States where it has often been used in the food and fibre sectors (Runsten & Key, 1996). In Africa contract farming was promoted between the 1930–1950s in the fruit and vegetable canning sectors. The spread of contract farming in Africa has been attributed to the higher returns earned by high-value crops and the impact of new technology (Clapp, 1994; Eicher & Staatz, 1998). The expansion of this institution has received much attention, and many evaluation studies and reviews have been conducted on different contract farming experiences in Africa and their advantages for small farmers (Glover, 1987, 1990; Kirsten & Sartorious; 2002; Little & Watts, 1994; Porter & Phillips-Howard, 1997; Watts *et al*., 1994).

However, these reviews have often made strong criticisms. In many schemes established so far contractual arrangements have not been advantageous to small farmers, and contract farming has been seen as just another means of exploitation, that forces the farmer to labour more extensively and intensively. It is argued that it secures farmers' labour and land while leaving them with a formal title to these factors of production, and that contract farming leads to loss of autonomy (Carney & Watts, 1990; Clapp, 1994; Glover, 1987; Sofranko *et al*., 2000; Watts, 1994). Others, however, hold the view that contract farming is a vehicle for modernization, since it provides small farmers the benefits of modern technologies, quality control, marketing and other services (World Bank, 1989). While the debate goes on, it nevertheless seems likely that the institution of contract farming will continue to grow as an important feature of rural Africa and as an important vehicle for keeping small farmers involved in markets. What seems to be important is to use the lessons from the experiences of contract farming to improve the working of the institution as a whole (Kirsten & Satorious, 2002). By taking this approach, one could identify key issues to address in order to make contract farming a viable institution also for small farmers.

In this chapter, we turn our attention to a first-time contract farming experience in sorghum production for the brewery in Ghana. Sorghum is an important staple cultivated by small farmers in northern Ghana and mainly consumed as food and local opaque beer. Although sorghum can be used in the brewery industry as a partial replacement for barley malt this potential has remained largely untapped in Ghana for almost the past two decades.

Guinness Ghana Breweries (GGB) is a multi-national company in Ghana which annually imports over 10,000 metric tonnes of barley malt valued at about US$ 3.5 million for use in its brewing activity. Following several investigations into the possibility of using sorghum as a raw material for the breweries, a suitable variety (Kapaala) was found in the country, and GGB decided to use Kapaala as a substitute for 25% of its barley imports. The decision to source sorghum locally to feed the brewery led to the beginning of the Guinness sorghum project, in which GGB set out to buy Kapaala from farmers using an out-growers' scheme. In 2001, certified seed was produced by seed growers in the three northern regions and given to farmers to produce grain in 2002. However most of the grain was rejected because of poor quality and GGB acquired only 10–12% of the total quantity they had targeted. Many farmers were forced to sell their grain on the local market. After this initial setback GGB adopted a different strategy in 2003 by using a consultant (an NGO) to coordinate, manage and supervise the project. However, various problems (outlined in the next section) were encountered once more.

The failure of these initial efforts to scale up sorghum production for industrial use is disappointing for several reasons. First, private sector interest in the crop would have boosted prospects for income among farmers living in these three most poverty-stricken regions of Ghana (Ghana Statistical Service, 2000). Second, success would have raised the status of sorghum to that of a cash crop. Third, private sector interest would have boosted research into the improvement and development of sorghum. Fourth, sourcing sorghum locally would potentially save the country a substantial amount of scarce foreign currency.

However, to ensure conditions for future success it is important to understand the circumstances surrounding previous failures. The case of the 'sorghum sourcing contract' in the Garu-Tempane district, Upper East region, set up to supply sorghum to GGB is documented and analysed. The chapter first provides background information on all the key-stakeholders, describing their roles and involvement. This is followed by narratives from each stakeholder concerning events, activities, and their engagement with the other stakeholders during the period of the contract. These narratives are then analysed in order to understand the problems encountered during the scheme. The analysis provides some guidance on issues to be addressed in future attempts at commercializing sorghum production in Ghana. A particular concern is with the role that might be played by applied scientific research under conditions of commercialization. In effect, we are interested in prospects for 'convergence of sciences' under market-driven conditions in an African setting. Convergence of sciences works on the principle that science plus an interacting configuration of relevant stakeholders is often required for agricultural development to improve the livelihoods of small African farmers (Hounkonnou, 2006).

Methodology

A case study approach was used in which a set of events was documented with a view to drawing appropriate conclusions about particular processes of sorghum commercialization. The Presbyterian Agricultural Station (PAS) in Garu-Tempane and the farmer groups they assist were selected for study, being one of the five nucleus farmer organizations involved in the out-grower scheme. One important objective of the Guinness sorghum project is to help rural farmers in the poor areas of northern Ghana to raise their incomes through sorghum production. Garu-Tempane is representative of such poor areas. It is located in north-east Ghana, described as one of the most resource-poor and poverty stricken areas of the country, faced with increasing population pressure, declining soil fertility, and a steadily deteriorating production environment (CSIR/ USAID, 1976; FAO/IFAD, 1989).

Multiple sources of data were used both to ensure accuracy of interpretation and induce alternative explanations of events from the range of stakeholders involved in the scheme. The stakeholders were: farmer groups, senior management and field workers of PAS, a manager/coordinator of the scheme working for Technoserve/ Ghana (TNS/GH), scientists from SARI, and a representative of the brewery unit of the brewery. The main sources of data were interviews, an arranged meeting between farmer and brewery representatives, and documents and archival records. These were used as follows:

(i) Individual interviews: open ended interviews were used to obtain information from representatives from PAS, TNS/GH, GGB and a scientist from SARI.
(ii) Group interviews: these were used to obtain information from field extension workers of PAS and from groups of farmers who had produced the sorghum grain for GGB. Farmer groups were male, female or mixed (the average size of a group was ten persons). In all, nine groups – with at least one from each of the five zones of the PAS operational area – were interviewed.
(iii) Meetings: the researcher participated in an interactive visit to the brewery company arranged between representatives of the brewery unit of GGB and six representatives of farmer groups and two agricultural field workers. This meeting provided information about the relations between the company and farmers.
(iv) Documents and archival records were consulted. These include correspondence, reports and minutes of meetings held between different stakeholders during and after the events that unfolded in the scheme.

Results and discussions

Stakeholders, their role, interests, and involvement in the Guinness sorghum project

Guinness Ghana Brewery (GGB)

Guinness Ghana Breweries is a brewing company established in Ghana for over 30 years. The company produces both alcoholic and non-alcoholic beverages using imported barley as its main raw material. In the mid 1980s it started exploring the possibility of using sorghum as a raw material. Because of these attempts to reduce its import bill, tests on locally sourced sorghum continued until, in 2000, an improved sorghum variety named Kapaala, officially released by SARI in 1996, was found suitable for malting by GGB.

Under the Guinness sorghum project, GGB contracted Technoserve Ghana (TNS/GH), a non-governmental organization (NGO), to supply 500 metric tonnes of Kapaala sorghum in the 2003 season. The main interest of GGB was to source locally produced sorghum of good malting quality in order to reduce its import bill.

Technoserve Ghana (TNS/GH)

Technoserve Ghana is an international NGO specializing in business opportunities for the rural poor. It has operated in Ghana for over 20 years, working with farmer-based organizations at the production, processing and marketing levels. TNS/GH's role in the project was to identify farmers and organizations with the capacity to manage an out-grower scheme. This capacity required assistance with land preparation, delivery of inputs, management, supervision, and collection of produce, as well as provision of input credit at harvest time. TNS/GH also had the responsibility to acquire funds to pre-finance the production of sorghum. They also monitored the entire production, post harvest cleaning and delivery chain up to the point that the sorghum was supplied to GGB.

Presbyterian Agricultural Station (PAS) – Garu

The Presbyterian Agricultural station in Garu, Upper East region, is a church-sponsored agricultural station located in northern Ghana. Established in 1967, its mission is to provide extension services to the farming communities in and around Garu in response to their efforts to attain food security. The station works with farmer groups and has from the 1970s helped to introduce new and improved varieties of cereals – especially maize and sorghum – to farmers. The role of the station in this out-grower scheme was to register farmers to produce Kapaala grain. The responsibilities of the staff included the monitoring of registered farmers to ensure proper field management practices, delivering inputs such as seeds and fertilizers, and collecting and assembling the grain after harvest.

Savannah Agricultural Research Institute (SARI)

SARI is the national agricultural research institute for the savannah zone of Ghana. The researchers include a team of scientists with expertise in breeding, crop protection, and agronomy whose mandate crops are cereals, and roots and tuber crops. Research efforts on sorghum have mainly concentrated on screening and making selections from local and germplasm introduced from ICRISAT and other international institutions. To date, SARI has released seven sorghum varieties, including Kapaala, the sorghum variety found suitable for brewing. Kapaala was developed and selected from ICSV111, an introduction from ICRISAT.

Farmer groups (producers)

Thirty farmer groups located within the Garu-Tempane district, Upper East region, were registered for Kapaala sorghum production. The group membership ranged from six to fifteen in number, with about 80% men and 20% women. These groups were established by PAS and were between 4–10 years old. They have been (or still are) supported by provision of training, credit and agricultural inputs to start income-generating activities. Such activities include the production and sale of crops like cotton, onions, maize, soybean, and livestock such as guinea fowls and small ruminants. After six years the structural support is withdrawn but the groups continue their activities and maintain contact with PAS. In the sorghum project farmers agreed to be responsible for producing, harvesting and making the grain available at the end of the season to GGB. Production was done on both a group and individual basis.

Narratives from actors

The narratives below are a summary of written reports and oral accounts of the events that unfolded in the Guinness Sorghum project during the 2003 and 2004 seasons. In the narrative each stakeholder provides his/her own account of their involvement. The section on GGB is not a narrative like the other ones since the brewery did not deal directly with any of the stakeholders and only worked through TNS/GH. Rather the section on GGB is a brief summary of their submissions during the interactive visit of the farmers to the company. Constructing a meaningful and accurate account from the narratives of events that unfolded was not a straightforward task because each interest group tried to improve its position through participating in the researcher's attempts at a reconstruction of events. Additionally, the reluctance of some stakeholders to provide information made it difficult to follow up unclear issues to uncover the complete story. A shortcoming of this study was the inability to interview any seed grower, i.e., suppliers of the certified seed for grain production. This was mainly due to the fact that the seeds were produced by several individuals at different locations and in a distant and different region (Northern region) from the region where this case was studied.

Guinness Ghana Brewery (GGB)

The Guinness Sorghum Project was set up in order to make use of locally grown sorghum for use as raw material for brewing beer. GGB's intention is to replace barley malt, imported from other countries, with sorghum malt and to reduce their importation bill, without a loss in quality. In the past they have imported sorghum from places like Malaysia and Nigeria but now that a suitable variety has been found in Ghana they intend to make use of this local source. At the moment GGB, with the assistance of UNDP (United Nations Development Project), is providing financial support to develop better ways of malting and brewing at the national Food Research Institute (FRI) in Accra, and to train farmers on efficient ways of malting sorghum for the brewery.

GGB has found the red sorghums used by farmers for malting and brewing *pito* unsuitable for its industrial purposes because of their high levels of polyphenols. Kapaala, on the other hand, has been found to be suitable. The grain quality of sorghum is the most important aspect to the brewery but this largely depends on the post harvest storage conditions, which also influences the level of aflatoxins (dangerous fungal toxins) and the moisture content of the grain. For now, GGB is getting less than 2% of the sorghum it requires per year for beer production in Ghana; it could use up to about 4000 metric tonnes/year of sorghum. This means that the amounts obtained under the project described in this chapter are as yet very inadequate. There is much scope for improvement in supply.

Interaction with some farmers – during a visit arranged by the researcher to GGB to give farmers the opportunity to know the company for which they were producing – has made the company aware of some details of the problems encountered. Before this visit, the company claimed that they had no feedback and the reports supplied were not detailed enough to provide a full picture. Even simple methods of convergence open up new perspectives.

Technoserve – Ghana

TNS/GH identified and contracted PAS as one of the organizations to manage the out-grower scheme in the Upper East region. Together with representatives from the Ministry of Food and Agriculture (MOFA) and farmer representatives, TNS/GH prepared a crop budget. This budget was the basis on which the farm gate price of Kapaala was fixed. This price was 2,900 cedis per kg (US$ 0.32), higher than the prevailing market price. A training workshop was organized by TNS/GH for farmers and other relevant stakeholders, to spell out what was required for the success of the scheme. Based on a production guide prepared by SARI, TNS/GH advised that seeds should be planted in a period from the end of June to mid-July (this was in the first year of production). However, TNS/GH did not know that this time was later than the normal planting time used by farmers, and simply tried to ensure that the farmers followed the instructions in the production guide. The NGO claimed that more than 50% of the seed sold through the MOFA seed inspection unit gave germination percentages from 0 to 30%. On average most farmers had to replant three times and in some cases replacement seed had to be purchased for replanting (TNS Final Report on Guinness Sorghum Production, 2003, p. 6–7; planning and planting stage). TNS/GH also found that the sorghum farms were attacked by insects and birds during the seed formation stage, and also by moulds. Furthermore, the rains, which normally cease by mid-October, continued later that year, making harvesting and drying difficult and creating a conducive environment for the grain moulds. Some farmers resorted to selective harvesting in order to salvage some of their crop. The yields were low and the total amount obtained fell far below the target. Within 4 days of collection, the grains were inspected, cleaned, and delivered to GGB. The quality of grain obtained was good and none was rejected by GGB. However, poor yields resulted in outstanding debts. In total, out of the 1.13 billion cedis (US$ 124, 421) loaned in the two regions under this project, a balance of about 1.11 billion cedis (97%) remained to be recovered at the end of the season.

Presbyterian Agricultural Station (PAS) – Garu

In 2003, the management of PAS entered into an agreement with TNS to organize, manage, and register farmer groups to produce Kapaala sorghum in an out-grower scheme. The production was designated to begin in the cropping season of the same year, which normally lasts between May and September/October. Interested farmers were registered. Certified seeds were delivered by TNS, which obtained them from seed growers in the Northern and Upper West region. Four kilos of seeds per acre were sold to farmers. Two bags of NPK chemical fertilizer and one bag of ammonium sulphate were given to farmers on credit. The inputs were to be paid back at 3% interest after harvesting the grain by deducting the cost from the income from the total grain produced. It was agreed with farmers that they would first clean the grain before it was collected. Payment would be made only after the grain had been delivered and sold to GGB.

PAS was told by TNS that planting should be done between the middle and end of June. PAS ensured that farmers stuck to this directive by monitoring their field activities. Apart from the usual agronomic practices for sorghum no specialized training was given to farmers on the production of Kapaala. Specific activities, such as sowing and fertilizer application, were supervised and monitored by PAS.

After sowing, farmers complained about poor germination, and some had to replant or fill in empty stands. During flowering and seed setting birds and head sucking insects attacked the crops in the field. The yields obtained were very low and out of a total anticipated target of 30 metric tonnes, only 5.65 metric tonnes was obtained. At the end of the season farmers were unable to repay the loan even after selling all the grain they produced.

After this first attempt many farmers were indebted, with no choice but to continue production for another year in order to pay back the credit they had already received. Some farmers suggested to PAS that the variety should be changed because it was too susceptible to insect pests, birds and moulds. They suggested that another variety cultivated by farmers and known as Dorado/Dolla, and very similar in plant and grain characteristics to Kapaala, should be tried. The suggestion was given to TNS who later collected grain samples and supplied them to GGB for suitability testing. When GGB found them appropriate the change was effected in the second year.

In the second year very little seed was available for sale to farmers. In addition to what PAS produced on-station, the NGO had to buy seed from any farmer who had

Dorado or Kapaala, after which the staff cleaned, sorted, and resold these varieties to other farmers who did not have sufficient seed. In the second year, the farmers received only seed, and no additional inputs or assistance, unlike in the previous year. However, farmers were allowed to choose the time to plant the two varieties. Although the yield improved it still fell below the mark. Additionally, because some farmers needed cash badly they could not wait for PAS to sell their grain to GGB before paying them money, so they sold on the open market.

The researchers (CSIR-SARI)

TNS made contact with representatives of SARI at the beginning of 2003, after agreeing to coordinate the Guinness sorghum project for GGB. SARI indicated their support for TNS and gave TNS sample sorghum crop budgets, that they had previously prepared with farmers, to help TNS determine the prices that would be charged for the sorghum grain. SARI's interactions with TNS took place within the first quarter of the year, after which a training workshop for farmers and other relevant stakeholders was held in June. The workshop was planned by TNS and brought together farmers, scientists from SARI, representatives of the Ghana seed inspection unit, MoFA (Ministry of Food and Agriculture), and some members of the Northern Sector Seed Growers association. SARI had provided technical advice to TNS in previous discussions and expected to be involved in the planning and execution of the project itself. Moreover, SARI was the producer of foundation seed, and knew that it would be required for producing certified seed for subsequent years in order for the project to continue beyond the first year of grain production. The seed growers and representative of the seed unit were also present at this meeting because of their role in supplying certified seed for the first year of Kapaala grain production. Seed growers are mandated to produce certified seed from foundation seed, for sale to farmers.

At this workshop TNS spelt out the criteria for selecting participants, indicating that participating farmers would be from the Northern and Upper East regions. SARI, however, advised that Upper West region should be included because this region was the best for Kapaala production. Although SARI had available 100 mini bags (5000 kg) of foundation seed TNS agreed to purchase only five bags (250 kg), at a total cost of three million cedis (US$ 330.3). This amount of foundation seed could yield about 22.5 tonnes of certified seed for planting 2250 ha of land (which seemed to be more than adequate for one production year for the entire number of farmers in the scheme, including farmers in Garu-Tempane). At a follow-up meeting in July, SARI questioned the rationale behind TNS's decisions and renewed appeals were made to TNS to reconsider the inclusion of the Upper West region and the purchase of more foundation seed produced specifically for producing certified seed. However, the NGO did not listen to these appeals, stating that, as an organization well versed in business matters, they had their own strategy and criteria for selecting who would participate in the sorghum project.

In the TNS strategy for the Guinness sorghum project SARI found their role in the project to be unclear and undefined. Furthermore, they did not sign any memorandum of understanding with TNS, GGB, and the producers. Thus, apart from providing a manual for Kapaala production, prepared at the time of releasing the variety, and the supply of foundation seed, SARI had no further involvement in the project. SARI attributed the failure of the project to TNS's refusal to heed technical advice and make use of the required inputs.

The farmers

The farmers were informed about GGB's demand for sorghum by PAS and those interested in growing the crop were registered to produce Kapaala in 2003. Before registration, farmers were told by PAS that 4 kg of seed would be sold on credit to each farmer (or group of farmers) to cultivate an acre of sorghum on an individual or group basis. Two bags of compound fertilizer and a bag of ammonium sulphate would be given per farmer/group on loan. Farmers were also told that, after harvesting, sorghum would be bought from them at the price of 2400 cedis per kg. Farmers who agreed to produce sorghum on these terms then registered their names but there were no documents written to this effect. In short, no written contract was negotiated or prepared at the farmer level.

Farmers normally plant their early maturing sorghum in May or by the first week in June, depending on when the rains actually begin. However, they were told by PAS that Kapaala required late planting (between middle and end of June). The seeds were supplied to some farmers before the end of June and most farmers sowed by the last week in June. Some farmers, however, experienced some dry spells around this period, and had to delay planting until the first or second week in July. Other farmers claimed that they received the seeds only in the first week of July and they sowed soon after.

> "*PAS gave us the seed and told us to sow end of June, but it failed completely*". (Source: My field interviews, Yabrago No. 1, 21/9/04)
>
> "*The seeds arrived first week of July and we sowed it but there was no rain. Those of us with enough seeds replanted and others only thinned and transplanted*". (Source: My field interviews, Biambogo, Yabrago No. 1, 16 and 21/9/04)

However, even farmers who planted by the end of June still considered the timing to be too late, explaining that they usually plant their early varieties (including Kapaala) in May or at the latest by the first week in June. No training was given to the farmers on Kapaala production, but PAS field agents visited their farms at planting and harvesting time to monitor their field activities. After sowing many farmers found that germination was poor and most of them had to replant or refill (for those who could not afford to buy more seed). Few problems were encountered during the vegetative stage. Fertilizers were applied to the field at the recommended rates and time. A few farmers reported that at the booting stage the rains did not come. At flowering stage a lot of insect pests were found in the fields. The farmers were helpless against these insect pests and did not spray. Two main types of insects were reported – sorghum midge (*Contarinia sorghicola*) and head bugs (*Eurystylus oldi* Poppius). Spittle bugs (*Aphrophora spp.*) were also reported. While not all farmers mentioned the spittle bugs, the midge and head bugs were reported by six of the nine farmer groups interviewed. They also observed that in the fields where the midge was found seed set was very poor, or entire panicles were devoid of seed.

> "*There were insects; red ones and also black ones when the crops flowered. There were no chemicals to spray, no seeds were formed on the heads and instead we had to use them for firewood or the children chewed them like sugarcane*". (Source: My field interviews, Yabrago, 21/9/04)
>
> "*Another problem was the insects. They were red in colour and all over [the field] and came when the crops were flowering, later we did not find any seeds on the head*". (Source: My field interviews, Biambogo, 16/9/04)

At harvest very little grain was obtained and others harvested nothing at all. There was no group in which all the farmers repaid loans fully at the end of the season. The majority either paid in part or could not pay at all. For such farmers their repayment period was extended for one more year in the hope that after another year of production they would be able to raise enough to pay their debt.

> "*We have not been able to pay the debt and PAS told us that this year's harvest will be used to pay for it*". (Source: My field interviews, Kpatia, Yabrago No. 1 21/9/04)
>
> "*None of us were able to sell any grain to PAS last year and all the group members still owe*". (Source: My field interviews, Yabrago No. 1, 21/9/04)

After this experience of poor performance, farmers suggested to PAS that Kapaala should be replaced with Dorado. Dorado is one of the sorghum varieties grown by farmers, and similar to Kapaala in its growth characteristics, agronomic requirements, and grain characteristics. Dorado has a more open panicle with slightly harder grains and reddish glumes. When both varieties are threshed it is difficult to distinguish between them. In terms of food quality, farmers do not find much difference between the two. Farmers say they obtained Dorado from villages bordering Togo and have been growing it for the past 6–8 years.

In the second year most farmers switched to Dorado when GGB agreed to their suggestion, although some persevered with Kapaala.

Unravelling the problem and factors contributing to the failure

The problem is considered to be two-fold: technical and institutional. The technical component was a combination of pest problems, the variety, and the environment.

The insect pests found in the fields (as reported by the farmers, PAS and the NGO) are all panicle pests of sorghum. But of the three that were mentioned, the head bug and midge are two key pests of sorghum important in West Africa (Ajayi *et al*., 2001; Harris, 1961; Ratnadass & Ajayi, 1995; Sharma *et al*., 1994; Young & Teetes, 1977) and especially in Ghana (Bowden, 1966; Tanzubil *et al*., 2005).

The sorghum midge

The midge is considered the most important of all the insect pests. Injury to the grain occurs after small orange-coloured female midges oviposit in the flowering spikelets. The eggs hatch into larvae in two days and the larvae feed on the contents of the developing spikelets, preventing grain set. This causes the spikelet to remain empty and dry. The larvae pupate in 9–11 days under the glumes and the adults emerge about 3 days later. A generation may complete in 14–16 days. The short development cycle permits as many as 9–12 generations within a single growing season, leading to a build-up of high midge populations, especially where flowering times are extended by a wide range of planting dates.

A detailed study on the midge and other causes of grain sorghum loss in Ghana was carried out in 1965 by Bowden. He found that temperature and relative humidity were very important factors in the phenology of the midge and its infestation levels. In the north-eastern part of Ghana, Bawku, the larvae start to go into diapause by early to late November when there is a sharp drop in ambient temperatures and the relative humidity is about 60%. The first early adult flies are found towards the middle of the rainy season, i.e., July and August. But by this time the only flowering heads available for oviposition are mainly volunteer crops or precocious tillers of the main crop. But the mass emergence of the main bulk of the adult fly occurs when temperatures are high (about 25–39 °C) and accompanied by a high relative humidity (about 94–100%).

Secondly, Bowden found an important relation between midge infestation and time of flowering of the main crop. When main flowering was early in the season, midge attack was very low (< 5%) or even non-existent, but as dates of flowering were delayed, the percentage of spikelets infested rose sharply. In fact, infestation increased three times as rapidly with each week's delay in flowering. An infestation of 81% was recorded in a late crop of sorghum. Bowden suggested that in order to avoid this mass emergence of adults from diapause, causing economic levels of damage to sorghum, the main flowering should be complete by late August or latest by early September in the north-east, and by mid-September in the middle belt (Northern region). One of Bowden's conclusions was that, in so far as Ghana is concerned, midge only became serious when the crop was delayed. But this also implied that planting should be early in order to satisfy this condition. The planting time worked back to the usual sowing time of May to June in north-eastern Ghana. But it was found that the problems arose when, frequently, farmers sowed only a portion of their land in good time, and then at a later date sowed the remaining portion of sorghum, having been diverted by other agricultural activities. These later sowings were always at risk of excessive midge damage.

It is important to note that Kapaala flowers in 65–72 days (Murty *et al.*, 1998). Therefore, if, as the narrative in this present study shows, farmers sowed Kapaala in late June or early July (in some cases), then their crops would have just begun to flower in September, when, according to Bowden, flowering should be completed in order to avoid midge risk. This makes the issue about planting and flowering date a very important one needing careful consideration. In the study area and in Bawku as a whole, labour availability also delays sowing and harvesting. During my interactions with farmers (see Chapter 2) and also in documenting this present case, farmers indicated that timely access to labour and lack of bullocks (oxen) for ploughing were important constraints to sorghum production and in farming in general. Therefore, apart from ensuring that there are no delays when supplying seed to farmers, it might be worth paying attention to constraints in farmers' access to land preparation facilities.

Head bugs

Head bugs (*Eurystylus oldi* Poppius) are the most important of all the mirids that feed on sorghum grain in West and Central Africa (Doumbia & Bonzi, 1985; McFarlane, 1989; Sharma *et al.*, 1992). The head bug varies in colour, ranging from brownish yellow to dark brown with red markings (Teetes & Pendleton, 2001). The female adults deposit their eggs on the panicles soon after booting and both the adults and nymphs suck sap from the developing grain. The sucking effect causes the grain to distort and shrink and thereby reduces yield. Apart from this, the bugs are often associated with grain moulds leading to quality losses in the grains attacked. Yield loss can be as much as 86% (ICRISAT, 1991) and it was thought by Bowden (1966) that the probable extent of damage caused by mirids may well be generally more severe than that occasioned by midge.

There is little information, however, on the incidence, distribution, and damage potential of head bugs on local and improved sorghum cultivars in farmers' fields in Africa. In one study conducted in West and Central Africa (Mali, Niger, Burkina Faso and Nigeria) it was found that head bug abundance is lower on landraces with long glumes than on improved cultivars (Ajayi *et al.*, 2001). Most of the landraces have loose panicles, which do not sufficiently protect against large numbers of the bugs. The long glumes cover the grains until the endosperm becomes hard enough to resist oviposition and feeding by head bugs. Furthermore, landraces flower in October when head bug populations start to decline because of low humidity (Sharma *et al.*, 1994). In contrast, many improved varieties in West and Central Africa are of the caudatum type, which have compact panicles, short glumes, and medium-hard to soft grains. Compact panicles, by their architecture, offer a micro-environmental effect that leads to a relatively stable and humid micro-climate for the bugs. This makes many improved varieties of the caudatum type more susceptible to head bugs than the local loose-panicle guinea landraces (Ratnadass *et al.*, 1994a, 1994b; Ratnadass & Ajayi, 1995).

The variety

Kapaala is a caudatum type of sorghum with semi-compact panicles. It has short glumes which cover about 25% of the mature grain, thus providing excellent conditions for head bug habitation, reproduction, and feeding. A recent study in northern Ghana by Tanzubil *et al.* (2005) on the damage potential of mirid bugs infesting sorghum panicles of Kapaala, Kobori (a local variety), and a head bug resistant variety from ICRISAT, showed that although all three suffered significant losses in grain yield and viability, Kapaala suffered the highest losses and the most shriveling. The above findings support the observation that Kapaala is susceptible to head bug infestation. This susceptibility is, however, already known to breeders and it is for this reason that a hybridization programme has been started to open up the panicle of Kapaala (see Chapter 2).

Apart from this, the variety is also known to be susceptible to precocious germination (pre-harvest sprouting). This problem usually arises especially when grain maturation occurs in rainy weather, leading to loss of seed viability and enhancing the development of grain moulds – a condition that adversely affects the quality of the grain. Sorghum genotypes are known to vary in susceptibility to pre-harvest sprouting (Maiti *et al.*, 1985). Therefore, if the TNS report about the occurrence of moulds is a fact, it raises a potential problem for farmers and ultimately for GGB, a problem which needs to be addressed in the future. There is a clear case here for introducing some science into the institutional environment of contract farming.

From the above discussions it is clear that a combination of pests, environmental conditions, and perhaps genotype contributed to the crop failure. This makes Kapaala production on a commercial scale a potentially risky business. But it also appears that not only were there technological problems but that the contractual arrangement itself presented a problem.

The contractual arrangement

A contract is a reflection of the relationships between the different stakeholders and involves an agreement between the parties involved (Little & Watts, 1994). However, in many cases, including instances in Africa, a contract is not always formalized, but remains a verbal agreement, or takes the form of simple registration (Eaton & Shepherd, 2001) to indicate understanding and compliance with the terms of agreement. This seems to undermine the potential of the contract as an instrument. According to Goodell (1980), the contract enables social unequals to negotiate and enter binding agreements as legal and political equals.

But in this study there is no evidence of negotiation between farmers and the company before they 'signed up' to produce Kapaala for GGB by registering their names with PAS field agents. Farmers did not know how the price was determined. Equally unknown to them was how soon collection and payment would be after harvesting, the penalties for defaulting, and the arrangement for compensation for crop losses or other contingencies. Rather than entering into a production agreement based on negotiation and knowledge of all relevant facts, it seems that farmers agreed to produce based on trust in PAS as an organization after several years of receiving support from them. It is in fact quite common to find that patron-client relationships, widespread in village life in West Africa between, for example, chiefs and commoners, or grain merchants and farmers (Richards, 1986), extend to relations between projects and participating farmers.

At a higher level, PAS had a more formal agreement with TNS and GGB in the form of a memorandum of understanding (on behalf of farmers), with GGB using TNS as an intermediary (see Figure 1). While GGB had no direct relationship with farmers, TNS did, and therefore had a crucial role in negotiating a viable contract between both parties. However, the NGO did not have the capacity to do so fairly because it lacked technical knowledge about the variety, its interaction with the environment, and the possible associated risks. In crop production, production risks arise from the uncertainties about the crop's performance and the unpredictable nature of the weather (Glover, 1994; Hardaker *et al*., 1997; Kirsten & Sartorious; 2002). A need to manage risk and uncertainty is one of the factors frequently advanced to explain why contract farming is first introduced, and it seems important that in dealing with the technical aspects of production the arrangements for sharing risk should be given as much attention as those for sharing profit (Bernal, 1997; Mighell & Jones, 1963).

Making technology development part of the contracting process

The sorghum variety in question is a relatively new and sensitive one whose cultivation becomes more complicated within the marginal and unpredictable environments faced by farmers in north-east Ghana. Contingencies are bound to arise. Therefore, how to anticipate and deal with them is an essential element in the contract. In effect we need to assess the role of technology development in the contracting process. In discussing the Ghana case, it may be helpful to draw attention to a similar case of contract farming in the Philippines.

In this south-east Asian production scheme for hybrid maize seed, the company (Pioneer Hi-bred Agricultural Technologies), contracted growers to produce certified seed for its market from foundation seed produced by company breeders in its research department. The cultural practice was prescribed in detail, and the company technicians closely interacted with farmers to monitor the seed production. Successful

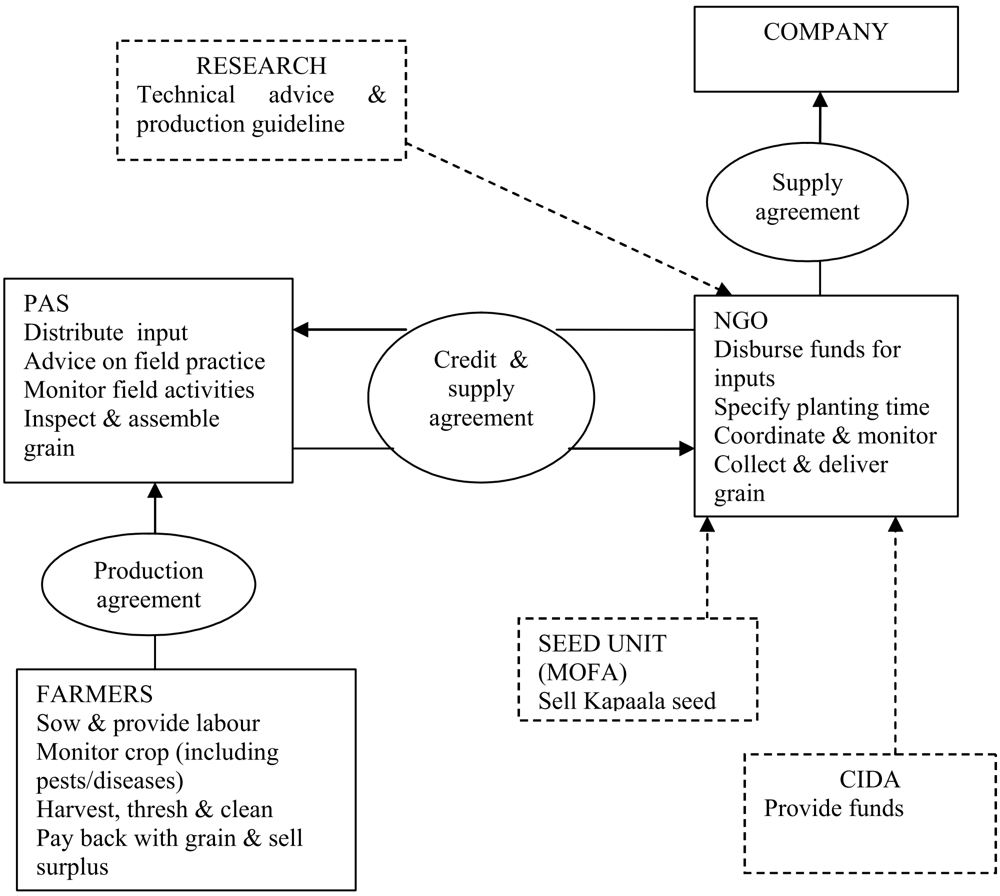

Figure 1. Stakeholders, their roles, divisions of tasks and agreements between parties involved in contract. (Note: stakeholders in dotted boxes are not part of the contract).

production was highly dependent on reliable irrigation at crucial stages of the plant growth. Because of the prolonged periods of dryness experienced in the growing area every year – leading to crop losses – an irrigation plant was constructed and an association was charged with the responsibility for ensuring fair distribution of irrigation water to all farmers, regardless of whether they were maize seed growers or not. The facility operated autonomously from the seed company. Also, the seed farms required the isolation of the production plots, a basic requirement in hybrid seed production, to avoid unwanted cross pollination. Therefore, a cropping pattern was designed by the company technicians and adopted by all the farmers in order to satisfy this requirement. But soon after the start of the scheme the opportunity arose to grow commercial maize and silage when cattle ranch owners moved into the area. This was a quicker and lucrative business. This alternative market for maize brought competition and interference with the production management required by the company's seed production operations. Aside from these constraining effects imposed by the external environment, the intrinsic qualities of the maize lines used in seed production posed another problem. The process of producing hybrid seed is very sensitive to drought from irregular precipitation and irregular water distribution, and leads to barrenness of the ear. High temperatures and low rainfall are particularly disastrous during flowering and pollination and these effects also differed according to the genotype supplied to farmers. Managing the genotype-environment interaction under adverse environmental conditions proved to be a major hurdle in seed production, and often led to crop failure, and failure interrupted the relationship between the growers and the company.

In his study of the hybrid maize case, Vellema (2002) found that crop management, irrigation management, and the quality of parent seed together constituted the 'technological reality' in seed production. Although researchers and breeders tried to find answers to the production problems by improving the technology, growers and technicians still had to cope with risks and uncertainties associated with unpredictable weather and uncertain crop performance. So long as the technology performed well and risks were compensated satisfactorily the company none the less was able to convince growers to continue production. In Vellema's view, the compensation for production risk can not be seen apart from the technological hardcore in the seed production process and he shows how the biological and technical elements strongly influenced the social relation between company and growers. Vellema's analysis flags the point that even though much depended on the capacity to use technical knowledge for practical purposes, interpretation, negotiation, and compromise could not be avoided by any of the parties involved in the contract.

It would seem that this present study can learn from the hybrid-maize case because here also, much depends on the interpretation of the technological problem and the institution of the contract itself. This is where science becomes important. Rather than parties becoming involved in a moralizing 'blame-game' discourse, what is required is a discourse of negotiation and re-negotiation of the contract based on hard evidence of the claims and counter claims made by farmers, PAS, and TNS about the technological causes of the crop failure. For example, it would be useful to carry out experiments to determine the optimum periods of midge attack in the sorghum producing regions and to determine what levels of loss are incurred from midge and head bug infestations. The information with regard to midge could be derived from an investigation of the combinations of moisture and temperature that induce and break diapause, through a series of trials over several seasons and arranged to give a spread of main flowering dates (cf. Bowden). Another issue would be to determine what actually happens when the rainfall delays planting or how different planting dates impact on yield of Kapaala in different parts of the region. With empirical data in hand it would be possible to check what farmers report about production problems. Another potential but longer term research could be the development of midge resistant and less bug-susceptible varieties. The role of science here would be not only to provide technological improvement but to give an objective interpretation of the pest problem so that it can be fed back into the re-negotiation of future contracts and debt settling. This is a role that can be undertaken by research (SARI).

The role of the NGO, in response, would be to abandon the current top-down extension approach, and to adapt a role as facilitator in the negotiation of a fair contract (that takes into consideration contingencies and anticipated problems) between GGB and farmers, based on the scientific evidence researchers generate about the technology. Essentially, the contract would have to include what to do, for example, when the rains do not come at the expected time, or what pest control measures farmers can be financially supported to adopt in order to ensure that all the environmental and technical uncertainties are not off-loaded unto the farmers.

The suggestion to replace Kapaala with Dorado should be seen as an attempt by farmers to reduce their production risk. Faced with debt, and left with no choice but to undertake a second year of production without financial support, farmers tried to negotiate for a variety they could manage better in their farming systems. Dorado is planted early and also has a more open panicle, which makes it less susceptible to head bugs. Drawing upon their knowledge about their portfolio of varieties (Chapters 3 and 4), they tried to find an alternative. GGB – and the private agro-business sector more generally – has not become fully apprised of the benefits of farmer participatory research and joint problem solving advocated by the convergence of sciences approach. But if a company like Pioneer Hi-bred is an organization that is willing to learn (Vellema, 2002), then listening and responding to farmers' knowledge is a potential way forward for stakeholders in the Ghanaian GGB process. Having direct and open lines of communication between farmers, company and researchers may be one way of responding. It appears this is already an option from the evident willingness of the company to respond positively to a suggestion from farmers. Clearly GGB knows what it wants, but how to get there becomes elusive under the circumstances. Perhaps more could be achieved, quickly and more certainly, by roping in an agency like SARI to undertake the research agenda suggested above and to interpret the evidence concerning technical failure correctly. For GGB, a link with SARI might extend as far as preparedness to invest in SARI research because ultimately the company stands to gain when the technology is improved. A key issue is to locate and understand the sites at which technology improvement might be undertaken, and to have relevant partners (including both researchers and farmers) capable of releasing technology bottlenecks. An objective would be to make a fair distribution of technological risks a part of the contracting process, and then to work on these risks in order to reduce them. Providing a specific place for technology development within the contracting process should make contracting more viable and attractive to all stakeholders.

Conclusion

The present case study provides an instance of contract farming where greater convergence around technological issues would apparently make a contract work better. Stakeholders and potential stakeholders in the contract – farmers, the brewery company, the NGO sector, and scientists – need to come together for specific negotiations over technological adaptation. It is suggested that by establishing the specific production problems and tuning in on them, a window can be opened for negotiation over contractual arrangements, with benefits for all parties. The failure documented in this account should be seen not as yet one more example of how farmers are failed by contract farming, but as an opportunity to mobilize both technical and farmer knowledge to improve technology, and thus to provide a basis for risk management that is fairer to all parties. The actual contents of the contract need to be spelt out clearly; risks and uncertainties associated with production need to be incorporated into agreements between farmers and the company and space created for negotiation or re-negotiation as adaptation takes place. The argument here is that by providing a specific place for science-based technology improvement within the contract framework, contracting can work to the benefit of all parties. It is not sufficient to make a general, context-free claim that "more research is required in order to correctly apply technology". What is needed is a commitment of all stakeholders in a specific sphere of interest to seek a better application of resources, skills and knowledge. Incorporating technological improvement within the contracting process serves to make initially poor bargains better. Contract farming is thereby shown to be a potential site for the convergence of sciences approach in which new and dynamic relationships can be created and sustained between the private sector, farmers, scientists and NGOs under market-driven conditions.

CHAPTER 8

Main research findings and general conclusions

This thesis has explored ways of conducting agricultural research using the Convergence of Sciences (CoS) approach within the context of sorghum genetic diversity, sorghum diversity management and variety maintenance, seed management and sorghum production under small-farmer oriented but increasingly market-driven conditions.

The underlying philosophy of convergence of sciences is the democratization of science in agricultural research based on trans-disciplinarity and interdisciplinarity. Therefore, to this end the CoS approach attempts the following:

- Recognizes and emphasizes the role of (multiple-)stakeholders in conducting useful research for, and with, those for whom it is intended;
- Recognizes that science is necessary for making agricultural research beneficial; but also
- Maintains the view that the interaction between and contribution of relevant stakeholders to the research process is key for successful research;
- Recognizes that the social and natural science disciplines work together in facilitating learning and generating knowledge for problem solving among stakeholders;
- Supports the view that this interactive process involving multiple-stakeholders can and should result in innovations (knowledge, technology, new forms of organization).

This way of thinking derives from the concern that agricultural research has, in the past, achieved sub-optimal benefits, especially for small-scale farmers in Africa. The products of scientific research have not always been relevant for the farmers for whom it was intended, because research has often failed to take into consideration the contexts and opinions of these farmers. Additionally, the prevailing conditions farmers find themselves in make it difficult to fully appropriate the technologies that are generated from agricultural research. It is therefore imperative that before researchers engage in research they take full cognizance of the problem/constraints and needs, as well as the opportunities and resources, small farmers have in order to make the right pre-analytic choices.

Technographic and diagnostic studies, two main tools that the proponents of convergence of sciences have developed to make explicit these pre-analytic choices, were used to determine what kind of research would be considered relevant for farmers. A technographic study (not reported in this thesis) was used to explore the technological landscape by looking at histories, markets, institutions, configuration of stakeholders and contextual factors at the macro-level. This provided a broad illumination of researchable issues requiring attention. The diagnostic study was then used to pay closer attention to the local context (based on the insights from the technography) by zooming in on what farmers consider important, so as to clearly define research priorities and in order that subsequent research reflected the priorities of farmers and other relevant stakeholders.

Main findings reviewed

The study set out to answer two main questions:

How and in what area(s) can farmers and scientists effectively engage in agricultural research towards a sustainable use and management of sorghum genetic resources in Ghana?

What lessons does the CoS approach provide for future efforts in designing and conducting research relevant for the conditions of small farmers in Ghana?

But in order to answer these questions four specific objectives, whose formulation was informed by the results of the diagnostic study (Chapter 2), were set.

- The first objective was to determine how farmers use and manage their sorghum varieties and the factors that influence this management.
- The second objective was to determine the genetic diversity of sorghum varieties managed by farmers.
- The third objective set out to determine farmers' knowledge and practices with regard to seed storage and diversity management in order to strengthen their capacity for variety maintenance and production of quality seed.
- The last objective was to explore how new relationships could be created and sustained between researchers, farmers and the private sector under market-driven conditions for sorghum production.

The way the thesis has addressed these objectives is summarized below. Chapter 2 offered a contextual overview, based on the technography study. The four main objectives listed above were then addressed in Chapters 3–7 as follows. Chapter 3 tackled the first objective using the results of a survey conducted in the district where the diagnostic study was conducted. Chapter 4 addressed the second objective while the third objective was addressed in Chapters 5 and 6. The last objective was addressed using a case study to analyse past and recent efforts by the private sector to scale up sorghum production in the study area (Chapter 7).

A brief summary of each of these main chapters is now offered. Chapter 2 focused on determining and defining the type of research that was considered useful for farmers by diagnosing their problems, constraints and opportunities in sorghum production. Within the prevailing cropping system sorghum was found to be a salient crop (apparently losing importance to maize), that forms an integral part of the lives of farmers in north-east Ghana. The importance and value of diversity were revealed through the different use values of the crop and the efforts made by farmers to manage and maintain their varieties in spite of constraining conditions such as inappropriate improved varieties supplied by the formal research sector, poor soils, erratic rainfall, storage pests and problems with seed quality. Farmers' efforts notwithstanding, the diagnosis showed the need to develop a research strategy to enhance farmers' knowledge and skills, so as to strengthen practices of diversity management and to improve seed storage. Ultimately, farmers' knowledge and management of plant variation and seed quality, and researchers' knowledge about sorghum genetic diversity and variety use and management by farmers, have been shown to be important for grasping the window of opportunity that opened through the growing interest of the private sector in the crop. The need was found to strengthen farmers' capacity by seeking not only to understand more about farmers' own knowledge about diversity and plant variation, but also to have in-depth knowledge about their sorghum germplasm base, how they managed and used their portfolio of varieties within their farming systems.

Chapter 3 brought to the fore the fact that throughout the Bawku-East district, farmers were maintaining a wide range of sorghum varieties. The chapter – based on a randomized survey of farmers across the district – was important in positioning the research on a more general spectrum of local interest in sorghum. An important finding was the fact that, among the list of cereal crops, sorghum held a prestigious place which was second only to millet. In spite of farmers' dissatisfaction with unfavourable rainfall conditions, late-maturing varieties of sorghum were still being cultivated. The high number of selection criteria considered important by farmers explained why farmers cultivated several varieties of sorghum. The maintenance of sorghum within the farming system of farmers in Bawku-East district was mainly attributed to a strong grain farming complex that was supported by beer brewing, labour provision, and traditional or religious festivals.

The insight or illumination about the importance and place of sorghum as shown by variety use and management leaned heavily on the application of quantitative and qualitative social science methods. However, further methods from the bioscience disciplines were used to establish the extent of diversity of varieties managed by farmers. In Chapter 4, classical agro-morphological characterization and molecular techniques were employed to assess the genetic diversity of sorghum germplasm held by farmers in the district. Both techniques showed that there was considerable genetic diversity among the varieties used by farmers, that could be useful for formal crop improvement programmes in Ghana. The high diversity found in panicle and grain characteristics, such as panicle compactness, grain colour, endosperm texture and endosperm colour, points to a readily available resource waiting to be tapped by the brewery whose main interest is in finding sorghum with specific grain characteristics and malting qualities for its products. While the intra-varietal variation found within panicles of sorghum varieties confirmed observations about varietal mixtures within farmers' field, it also lent further support to the need to assist farmers to enhance their skills in variety maintenance and in managing variation, in order not to lose this important diversity.

Chapters 5 explored the idea of convergence between stakeholders by showing how farmers and researchers could engage in a process of scientific experimentation, undertaken to investigate inter-varietal, intra-varietal, and random variation in sorghum. The use of an experimental framework (rather than a purely discursive one) to foster interaction between the knowledge systems of farmers and researchers facilitated better understanding and exchange of ideas. Researchers also sought to interrogate farmers' concepts of variety and variation. The joint learning and interaction provided evidence that

(i) a systematic exploration of scientific and local ideas, aimed at discovering points of overlap, might help farmers better to link their management practices to variation revealed through experimentation; and
(ii) this overlap in knowledge becomes more apparent when, in application of the theory of practice of CoS, farmers take part in scientific experimentation.

In Chapter 6, farmers and researchers engaged in more participatory research to evaluate farmers' seed storage practices using the same science-based approach based on experimentation in order to test the physiological quality of farmer-stored seed. The outcome of the experiment showed that generally, irrespective of the storage method used, the quality of farmers' seed was good. However, there was a significant difference in germination percentages among sorghum varieties, with the early-maturing varieties showing lower germination than the late-maturing varieties. The analysis showed that, especially for their early-maturing varieties, farmers needed to pay closer attention to the conditions under which harvesting, seed selection, and storage occurred. Of great relevance was the fact that through farmers' own analysis (facilitated and stimulated by researchers) of test data, they arrived at correct inferences, displayed their ability to contribute meaningfully to research, and helped widen the scope to research's effectiveness. This experiment is especially important for farmers who want to take advantage of the market avenue opened by the GGB's demand for such a sensitive early-maturing variety as Kapaala. Such farmers would need to take the lessons from these seed quality tests seriously in order to meet production standards and deliver quality grain to the brewery.

Chapter 7 explored the prospects for convergence of sciences under market-driven conditions for producing sorghum on a commercial scale. The failures in recent efforts to contract farmers for sorghum production for the brewery were analysed in order to derive suggestions for making contract farming fair and viable. The making of contractual arrangements and the application of the technology (variety) in question were identified as two key elements crucial for success. The role of science was considered essential for identifying and clarifying the research agenda in order to improve the technology, to make it work under the given environmental conditions, and to identify and share the associated risk factors which farmers cope with. The knowledge possessed by farmers was found to be germane for finding appropriate varieties for the brewing industry but also that it needs support from scientific research. The private sector's potential role as an investor in research in order to improve the technology was highlighted, as well as the need for the company to respond to scientific evidence about associated risks by ensuring a fair distribution of these risks within the contractual arrangements with farmers and other stakeholders.

General conclusions

The technography and diagnostic studies showed that sorghum is still important for farmers, even though at the outset the growing importance of maize as a food crop seemed to suggest that sorghum was losing its significance. The results of the diagnostic study presented in Chapter 2 and the subsequent chapter on variety use and management by farmers, left no doubts that sorghum plays a pivotal role in the social life, agrarian life, and culture of the small farmers in north-east Ghana. The value of genetic diversity for farmers, as revealed through the diagnostic study, provided strong justification for placing emphasis on, and pursuing research into two main areas: the need to support farmers' own efforts in diversity management and variety maintenance, and – as an important component of that aspect – the need to pay attention to farmers' seed management and storage practices. To do so effectively it was necessary to first determine what farmers knew, in order to find points of variance or convergence, and to establish effective ways through which interaction between farmer knowledge and scientific knowledge could occur.

Figure 1 provides a schematic summary of how stakeholders, disciplines, and research issues are linked within the 'theatre of sorghum genetic resource management'. The main research areas requiring attention that were identified in the preliminary stages were seed quality aspects, diversity management, and genetic diversity and production. The important stakeholders identified were farmers, scientists, and the private sector (a non-governmental organization and the brewery). In this study farmers and scientists engaged in research by means of a joint learning experimental framework, but another level of interaction is envisaged whereby farmers, scientists and the private sector can also interact and together develop sustainable relationships under market conditions for technology development. It was argued in Chapter 7, that contract farming can form such a theatre for convergence. The important issue is to ensure that the contracting process is open to science-based technological discovery.

Scientific methods and tools from the biological and social science disciplines were also required for gathering and analysing qualitative and quantitative data during the joint learning and experimentation phase of the study and for generating knowledge. Molecular marker techniques from the bioscience discipline were needed to ascertain

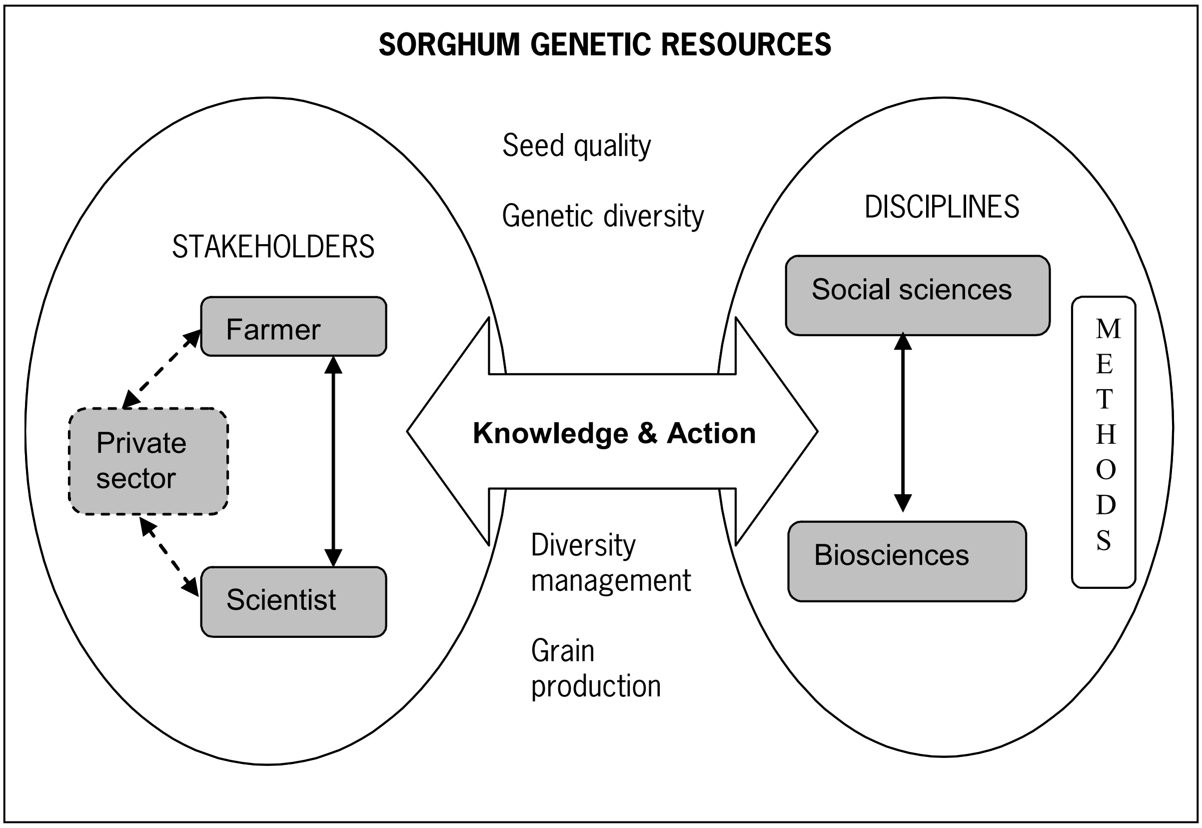

Figure 1. A schematic diagram of the linkages between stakeholders, areas, and disciplines in the research.

the extent of diversity used by farmers, while anthropological data were required to enrich our understanding of how cultural and socio-economic factors influence farmers' use and management of sorghum varieties.

The brewery's interest supports and advances the argument that research attention and effort for sorghum should be intensified, and shows why scientists need to support farmers' management by helping them to understand variation in sorghum. For example, farmers' deliberate strategies to reduce varietal mixtures in their field are important for maintaining purity, which adds market value to grain and seed. Apart from placing emphasis on variety maintenance and the knowledge and practices of farmers in managing diversity, the budding interest of the private sector in sorghum underscored the fact that emphasizing the development of improved, appropriate and adapted sorghum varieties was equally necessary. The importance of science for crop improvement is also considered germane to improve the livelihoods of small farmers who stand to gain a lot from producing 'technologically sound' varieties of sorghum under market-driven conditions. The benefits that could accrue to farmers under contract farming in the form of credit and material inputs (improved seeds and fertilizer), plus the presence of an assured market whose demand outstrips current supply all combine to make a strong case for investing in research towards developing better performing and appropriate sorghum varieties. Willingness of all parties to make research-guided technology-improvement a factor in contract farming agreements seems an important area for the convergence of science approach. Under such an adequately supported and higher input production environment small farmers stand a greater chance of deriving optimal benefit from improved varieties than they had in the past.

This thesis has suggested an approach through which researchers and farmers can work together to make use of scientific and farmer knowledge for diversity management. It suggests that joint experimentation under local conditions is a useful and effective means through which unschooled small-scale farmers and scientists can actively engage in the research process. Such an approach provides the opportunity for an intensive and sustained interaction between both farmers and scientists. Going along the pathway of joint learning and experimentation has shown that farmers are capable of joining in scientific research, have an indigenous capacity for astute observation, and are capable of forming a good working notion of science as it is practised in the formal sector. However, a conscious effort must be made to embed these scientific principles in the farmers' local and cultural context in order to make the capability of farmers as co-researchers become more apparent and present on a sustainable basis. It is suggested, however, that the usefulness of this kind of action research, both to farmers and the wider community is hinged to maintaining scientific standards. Therefore the challenge is one of keeping a delicate balance between having a good experimental design that is recognizable and useful in the scientific world and – and at the same time – is acceptable and useful and engaging of interest and enthusiasm in farmers' conditions.

This practice of cooperative inquiry which relies on science-based experimentation – in which scientists and farmers work together as co-researchers to exert influence on the research process – is seen as a prospective ally of other participatory approaches to technology development such as Farmer Field Schools which are based on the learning-by-doing principle. In effect, the use of a joint experimental framework need not become limited to agricultural researchers alone but could become useful for non-governmental organizations (NGO) sectors mainly interested in development work. The advantage is that the chances of scaling out the results become higher because while researchers are few and can work only with a few farmers at a given time, NGOs have the capacity to reach many more farmers. Extending this approach to NGOs could also provide the opportunity to generate large useful data bases for the scientific community at large. What is proposed here is a form of Research–NGO liaison in which researchers partner with local development agencies with the required scientific expertise to engage in and provide research support for farmers in order to facilitate local innovation. It has been the view of some in the past that the sooner action-oriented agencies (like NGOs) began working with universities and research institutes, the greater the likelihood for an improved human condition worldwide. Perhaps convergence of sciences offers the opportunity for such possibilities.

Perhaps one of the most striking findings uncovered by the technographic and diagnostic studies was that the private sector, and not just scientific institutes or NGOs, is a potential player in Ghana's agricultural research sector. It has been pointed out that in addition to identifying potential stakeholders who can work together to advance agricultural development, it is also essential to build the required relationships between such stakeholders to facilitate the emergence of innovations (Hounkonnou *et al*., 2006). The lessons learnt from assessing recent failures in efforts to commercialize sorghum production in Ghana stress the fact that farmers' energy, intelligence and innovative capacity are likely to remain stifled if we cannot find ways to change the patron-client relationships that are often transferred to many projects in parts of rural West Africa. In the NGO's approach to doing contract farming, a patron-client relationship seems to have been adopted whereby the technology must function only if it is accepted as a complete package and in which the client (farmers) only benefits from following instructions. But, in the 'theatre of *in situ* technology development' for sorghum genetic resource management, what is likely to be more successful, is a type of collegial relation in which cooperative inputs are required from all stakeholders.

While such a desired relationship seems to be within reach at the farmer-researcher level (but needs to be sustained), more work is required at the farmer-researcher-private sector level. The case of contract farming illustrates the important lesson that making contract farming work is often contingent upon mobilizing both technical and farmer knowledge for technological problem solving. Making technology part of the contracting process helps reinforce among all contracting parties the need to work jointly towards effective solutions to production problems in an uncertain world where effective new knowledge is at a premium. This requires the recognition by contracting companies of the fact that where the technology is an important problem, offering ways of bargaining or negotiating about the various contributions of relevant parties in the contract would lead to better application of technology.

In conclusion, convergence of science, as an alternative approach to the linear model of planning, designing and implementing research, appears to hold much promise for small farmers such as those found in the north-eastern part of Ghana. Even though sorghum has not been top on researchers' agenda in the past it remains an important crop for farmers who stand to gain a lot more if researchers commit and apply themselves to partner with farmers as co-researchers. This thesis has thrown some light on how such partnerships for new and effective knowledge might evolve.

References

Abdi, A., Bekele, E., Asfaw, Z. and Teshome, A. (2002). Patterns of morphological variation of sorghum (*Sorghum bicolor* (L.) Moench) landraces in qualitative characters in North Shewa and South Welo, Ethiopia. *Hereditas* 137: 161-172.

Abidin, P.E. (2004). *Sweetpotato breeding for northeastern Uganda: Farmer varieties, farmer participatory selection, and stability of performance.* PhD thesis, Wageningen University, Wageningen, 152 pp.

Agrama, H.A. and Tuinstra, M.R. (2003). Phylogenetic diversity and relationships among sorghum accessions using SSRs and RAPDs. *African Journal of Biotechnology* 2(10): 334-340.

Ahmed, M.M., Sanders, J.H. and Nell, W.T. (2000). New sorghum and millet cultivar introduction in sub-Saharan Africa: impacts and research agenda. *Agricultural Systems* 64: 55-65.

Ajayi, O., Sharma, H.C., Tabo, R., Ratnadass, A. and Doumbia, Y.O. (2001). Incidence and distribution of the sorghum head bug, *Eurystylus oldi* Poppius (Heteroptera: Miridae) and other panicle pests of sorghum in West and Central Africa. *Insect Science and its Application* 21: 103-111.

Albert, H., Bisset, P. and Marfo, K.O. (2000). Introducing Farming Systems Research in a National Agricultural Research Institute: Experience at the Savanna Agricultural Research Institute, Nyankpala, Ghana. A report prepared for GTZ, 86 pp.

Aldrich, P.R. and Doebley, J. (1992). Restriction fragment variation in the nuclear and choloroplast genomes of cultivated and wild *Sorghum bicolor*. *Theoretical and Applied Genetics* 85: 293-302.

Alhassan, R. and Jatoe, J.B.D. (2002). Adoption and impact of improved cereal varieties in Ghana. Paper prepared for the Workshop on the Green Revolution, in Asia and its transferability to Africa. 8–10th December. Foundation for Advanced Studies in International Development (FASID), 16 pp.

Almekinders, C.J.M. (2001). Management of crop genetic diversity at community level. Report prepared for GTZ, 53 pp. Online document. http:/www.gtz.de/agrobiodiv/download/almekind. Accessed [10/4/06].

Almekinders, C.J.M. and Louwaars, N.P. (1999). *Farmers' seed production: New approaches and practices*. London: Intermediate Technology Publications.

Almekinders, C.J.M. and De Boef, W.S. (2000). *Encouraging diversity: The conservation and development of plant genetic resources*. London: Intermediate Technology Publications.

Almekinders, C.J.M. and Elings, A. (2001) Collaboration of farmers and breeders: Participatory crop improvement in perspective. *Euphytica* 122: 425-438.

Almekinders, C.J.M., Louwaars, N.P. and De Bruijn, G.H. (1994). Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* 78: 207-216.

Amanor, K. (1990). *Analytical abstracts in Farmer Participatory Research.* Agricultural Adminstration Unit Occasional Paper 10. London: ODI.

Amanor, K., Wellard, K., De Boef, W. and Bebbington, A. (1993). Introduction. In: De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) *Cultivating knowledge: Genetic diversity, farmer experimentation and crop research*. London: Intermediate Technology Publications, pp. 1-13.

Anonymous (1994a). Ghana – National Agricultural Research Strategic Plan (1994). Final report. Accra: CSIR, 266 pp.

Anonymous (1994b). National Agricultural Research Project. Report on Cereals. Accra: CSIR, 248 pp.

Anonymous (1997). Cereals. Volume 1. A report by the Commodity Committee of National Agricultural Research Project (NARP), 48 pp.

Anonymous (2000). Towards sustainable agricultural development: Research and development options for improved integrated water management for agriculture of the Upper East Region of Ghana. Working Document No 85. International Centre for Development Oriented Research in Agriculture (ICRA), Wageningen, 107 pp.

Anonymous (2001). Project Document 'Convergence of Sciences: Inclusive technology innovation processes for better integrated crop and soil management'. International Research and Education Fund (INREF), Wageningen University, Wageningen, 52 pp.

Archibald, S. and Richards, P. (2002). Conversion to human rights? Popular debate about war and justice in central Sierra Leone. *Africa* 72(3): 339-367.

Atokple, I.D.K. (1993). An overview of sorghum and millet improvement in Ghana. In: *Improvement of cropping systems in the savanna zone: The challenges ahead.* Proceedings of the 3rd Workshop on Improving Farming systems in the Interior Savanna Zone of Ghana, 27–29 April, 1993, pp. 91-99.

Atokple, I.D.K. (1995). Current progress towards the utilization of sorghum in brewing lager beer in Ghana. In: Menyonga, J.M., Bezureh, T., Nwasike, C.C., Sedgo, P.M. and Tenkouano, A. (eds.) *Processing and industrial utilization of sorghum and related cereals in Africa*. Ouagadougou: OAU/STRC-SAFGRAD, pp. 61-69.

Atokpke, I.D.K. (2003). Sorghum and millet breeding in West Africa in practice. In: Belton, P.S and Taylor, J.R.N. (eds.) *The proteins of sorghum and millet:*

Enhancing nutritional and functional properties for Africa. Pretoria: AFRIPRO, pp. 137-148.

Ayana, A. and Bekele, E. (1998). Geographical patterns of morphological variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Ethiopia and Eritrea: Qualitative characters. *Hereditas* 129: 195-205.

Ayana, A., Bryngelsson, T. and Bekele, E. (2000). Genetic variation of Ethiopian and Eritrean sorghum (*Sorgum bicolor* (L.) Moench) germplasm assessed by random amplified polymorphic DNA (RAPD). *Genetic Resources and Crop Evolution* 47: 471-482

Baniya, B.K., A. Subedi, A., Rana, R.B., Paudel, C.L., Khatiwada, S.P., Rijal, D.K. and Sthapit, B.R. (2000). Seed supply system: Nepal. In: Jarvis, S., Sthapit, B. and Sears, L. (eds.) *Conserving agricultural biodiversity* in situ*: A scientific basis for sustainable agriculture.* Rome: IPGRI, pp. 159-164.

Bartlett, A. (2004). Entry points for empowerment. CARE Report, Bangladesh, 68 pp.

Basu, R.N. (1995). Seed viability. In: Basra, A.S. (ed.) *Seed quality: Basic mechanisms and agricultural implications*. New York: The Haworth Press, pp. 1-32.

Bellon, M.R. (1991). The ethnoecology of maize variety management: A case study from Mexico. *Human Ecology* 19: 389-418.

Bellon, M.R. (2001). Participatory research methods for technology evaluation: A manual for scientists working with farmers. Online document. http://www. cimmyt. mx/Research/Economics/map/research tools/manual/pdf. Accessed [29/4/2002].

Bellon, M.R. and Brush, S.B. (1994). Keepers of maize in Chiapas, Mexico. *Economic Botany* 48: 196-209.

Bellon, M.R. and Smale, M. (1998). A conceptual framework for valuing on-farm genetic resources. *CIMMYT Economics Working Paper*, 98-05.

Bellon, M.R., Pham, J.L. and Jackson, M.T. (1997). Genetic conservation: a role for rice farmers. In: Maxtead, N., Ford-Loyd, B.V. and Hawkes, G.J. (eds.) *Plant conservation: The in situ approach*. London: Chapman and Hall, pp. 263-289.

Benneh, G. (1972). Systems of agriculture in Ghana. *Africa* 43(2): 134-146.

Bentley, J.W. and Rodriguez, G. (2001) Honduran folk entomology. *Current Anthropology* 42(2): 285-301.

Berg, T. (1993). The science of plant breeding - support or alternative to traditional practices? In: De Boef, W., Amanor, K. and Wellard, K. (eds.) *Cultivating knowledge: Genetic diversity, farmer experimentation and crop research.* London: Intermediate Technology Publications, pp. 72-77.

Bernal, V. (1997). Colonial moral economy and the discipline of development: The Gezira scheme and modern Sudan. *Cultural Anthropology* 12(4): 447-479.

Bhuktan, J., Denning, G. and Fujisaka, S. (1999). Rice cropping practices in Nepal:

Indigenous adaptation to adverse and difficult environments. In: Prain, G., Fujisaka, S. and Warren, M.D. (eds.) *Biological and cultural diversity: The role of indigenous agricultural experimentation in development*. London: Intermediate Technology Publications, pp. 6-31.

Biggs, S.D. (1989). *Resource-poor farmer participation in research: A synthesis of experiences from nine agricultural research systems*. OFCOR Comparative Study Paper, No 3, The Hague: ISNAR.

Biggs, S. and Farrington, J. (1991). *Agricultural research and the rural poor: A review of social science analysis*. Ottawa: IDRC.

Bishaw, Z. (2004). *Wheat and barley seed systems in Ethiopia and Syria*. PhD thesis, Wageningen University, Wageningen, 383 pp.

Bowden, J. (1966). Sorghum midge, *Contarina sorghicola* (Coq.) and other causes of grain sorghum loss in Ghana. *Bulletin* of *Entomological Research* 56: 169-89.

Brown, S.M, Hopkins, M.S., Mitchell, S.E., Senior M.L., Wang, T.Y., Duncan, R.R., Gonzalez-Candelas, F. and Kresovich, S. (1996). Multiple methods for the identification of polymorphic simple sequence repeats (SSRs) in sorghum [S*orghum bicolor* (L.) Moench]. *Theoretical and Applied Genetics* 93: 190-198.

Bruin, G. and Meerman, F. (2001). *New ways of developing agricultural technologies: The Zanzibar experience with participatory Integrated Pest Management*. Wageningen University, Wageningen, 167 pp.

Carney, J.A. and Watts, M. (1990). Manufacturing dissent: Work, gender, and the politics of meaning in a peasant society. *Africa* 60(2): 207-241.

Ceccarelli, S., Grando, S., Amri, A., Asaad, F.A., Benbelkacem, A., Harrabi, M., El-Einen, R.A., El-Felah, M., El-Sayed, A.F., Shreidi, A.S. and Yahyaoui, A. (2001). Decentralized and participatory plant breeding for marginal environments. In: Cooper, D., Spillane, C. and Hodgkin, T. (eds.) *Broadening the genetic basis of crop production*. Wallingford, Oxon: CABI, pp. 115-135.

Chalfin, B. (2001). Border zone trade and the economic boundaries of the state in north-east Ghana. *Africa* 71(2): 202-224.

Chambers, R. (1992). Methods for analysis by farmers: The professional challenge. Paper presented at the 12th Annual Farming Systems Symposium, Association for Farming Systems Research/Extension, 14-18 September, 1992, Michigan State University, East Lansing.

Chambers, R. (1993). *Challenging the professions: Frontiers for rural development*. London: Intermediate Technology Publications.

Chambers, R. and Jiggins, J. (1987a). Agricultural science for resource-poor farmers Part I: Transfer-of-technology and farming systems research. *Agricultural Administration and Extension* 27: 35-52.

Chambers, R. and Jiggins, J. (1987b). Agricultural science for resource-poor farmers. Part II: A parsimonious paradigm. *Agricultural Administration and Extension* 27: 109-128.

Chankanda, R. (2000). *Farmers' seed systems for sorghum in Mali: An evaluation of farmers' variety characterization criteria.* MSc thesis Wageningen University, Wageningen, 67 pp.

Clapp, R.A.J. (1994). The moral economy of the contract. In: Little, P.D. and Watts, M.J. (eds.) *Living under contract: Contract farming and agrarian transformation in Sub-Saharan Africa*. Madison: University of Winconsin Press, pp. 78-94.

Cleveland, D.A. (1986). The political economy of fertility regulation: The Kusasi of savanna West Africa (Ghana). In: Handwerker, W.P. (ed.) *Culture and reproduction: An anthropological critique of demographic transition theory*. London: Westview Press, pp. 263-293.

Cleveland, D.A. (1989). Developmental stage age groups and African population structure: The Kusasi of the West African Savanna. *American Anthropologist* 91(2): 401-413.

Cleveland, D.A. (1991). Migration in West Africa: A Savannah village perspective. *Africa* 61(2): 222-245.

Cooper, D., Vellve, R. and Hobbellink, H. (eds.) 1992. *Growing diversity: Genetic resources and local food security.* London: Intermediate Techonology Publications.

Cornwall, A., Guijt, I. and Welbourn, A. (1994). Acknowledging process: methodological challenges for agricultural research and extension. *Agriculture and Human Values* 11(2-3): 38-57.

Cromwell, E. and Oosterhout, V.S. (1999). On-farm conservation of crop genetic diversity: policy and institutional lessons from Zimbabwe. In: Brush, S. (ed.) *Genes in the field: On-farm conservation of crop diversity*. Boca Raton: Lewis Publishers, pp. 217-238.

Cromwell, E., Wiggens, S. and Wentzel, S. (1993). *Sowing beyond the state: NGOs and seed supply in developing countries.* London: ODI.

CSIR/USAID (1976). *Proceeding of the first Seminar on the Joint CSIR/USAID North-east Ghana Savanna Research Project*. Kumasi: Council for Scientific and Industrial Research.

Dakurah, A.H., Kipo, T., Aflakpui, G.K.S., Allou, P.S., Dankyi, A.A., Marfo, K.A. and Von Bargen, J. (1992). Farmers' preference for maize/sorghum varieties in Northern Ghana: Results from a formal survey. Paper presented at the 12th National maize and legumes workshop, Ghana Grains Development Project, Kumasi, Ghana. 24-26 March.

Dankyi, A. and Dakurah, H. (1993). Cowpea technology adoption in Ghana. Crops

Research Institute, Kumasi, Ghana.

De Boef, W. and Almekinders, C.J.M. (2000). Introduction. In: Almekinders, C.J.M. and De Boef, W.S. (eds.) *Encouraging diversity*: *The conservation and development of plant genetic resources*. London: Intermediate Technology Publications, pp. xxix–xxxiii.

De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) (1993). *Cultivating knowledge: Genetic diversity, farmer experimentation, and crop research*. London: Intermediate Technology Publications, 206 pp.

De Oliveira, A.C., Richter, T. and Bennetzen, J.L. (1996). Regional and racial specifications in sorghum germplasm assessed with DNA markers. *Genome* 39: 579-587.

Demissie, A. and Bjornstad, A. (1996). Phenotypic diversity of Ethiopian barleys in relation to geographical regions, altitudinal range, and agro-ecological zones: As an aid to germplasm collection and conservation strategy. *Heriditas* 124: 17-29.

Deu, M., Gonzalez-de-Leon, D., Glaszman, J.C., Degremont, I., Chantereau, J., Lanaud, C and Hamon, P. (1994). RFLP diversity in cultivated sorghum in relation to racial differentiation. *Theoretical and Applied Genetics* 88: 838-844.

Dickson, K.B. and Benneh, G. (1988). *A new geography of Ghana*. London: Longman.

Dje, Y., Forcioli, D., Ater, M., Lefèbvre, C. and Vekemans, X. (1999). Assessing population genetic structure of sorghum landraces from North-western Morocco using allozyme and microsatellite markers. *Theoretical and Applied Genetics* 99: 157-163.

Dogget, H. (1988). *Sorghum*. 2nd Edition. London: Longman.

Dorward, A., Kydd, J., Morrison, J. and Urey, I. (2004). A policy agenda for pro-poor agricultural growth. *World Development* 32(1): 73-89.

Douglas, M. (1975). *Implicit meanings: Essays in anthropology*. London: Routledge.

Doumbia, Y.O. and Bonzi, S.M. (1985). Note sur les problèmes des insects des panicules du sorghum au Mali. In: Proceedings of the West African Regional Sorghum Network Workshop, 21–24 Oct, 1985. Ougadougou: SAFGRAD, pp. 173-182.

Durkheim, E. (1912). *The elementary forms of religious life*. 2001 Translation by Carol Cosman. New York: Oxford University Press.

Eaton, C. and Shepherd, A.W. (2001). Contract farming: partnerships for growth. *FAO Agricultural Services Bulletin 145*, FAO, Rome.

Eicher, C.K. and Staaz, J.M. (1998). Agricultural transformation and rural economic development: introduction. In: Eicher, C.K and Staaz, J.M. (eds.) *International Agricultural Development*. Baltimore: John Hopkins Press.

Evenson, R.E and Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960-2000. *Science* Vol. 300 Online document. www.sciencemag.org. Accessed before [3/3/06].

Eyzaguirre, P. and Iwanaga, M. (eds.) (1996). *Participatory plant breeding.* Proceedings of a workshop on participatory plant breeding. 26–29 July 1995, Wageningen, The Netherlands. Rome: IPGRI.

Eyzaguirre, P., and Iwanaga, M. (1996). Farmers' contribution to maintaining genetic diversity in crops, and its role within the total genetic resource system. In: Eyzaguirre, P. and Iwanaga, M. (eds.) *Participatory plant breeding*. Proceedings of a Workshop on Participatory Plant Breeding. Wageningen, 26–29 July 1995. Rome: IPGRI, pp. 9-18.

FAO (1996). *The world sorghum and millet economies: Facts, Trends and Outlook*. A joint study by the Basic Foodstuffs Service, FAO Commodities and Trade Division and the Socio-economics and Policy Division. ICRISAT and FAO. pp. 68.

FAO (1999). Women – users, preservers and managers of agrobiodiversity. Online document. http://www.fao.org/sd/LINKS/women. Accessed [12/4/2002].

FAO (2004). Local knowledge as part of agrobiodiversity. Online document. ftp://ftp.fao.org/docrep/fao/007/y5629e/y5629e00.pdf. Accessed [3/4/2006].

FAO/IFAD (1989). *Upper East Agricultural Intensification Project*. Preparation Mission, 2 vols. 149/89, IF-GHA 26. Rome: FAO.

Farnworth, C., Rozel, C. and Jiggins, J. (2003). *Participatory plant breeding and gender analysis*. Cali, Colombia: CGIAR Systemwide Program on Participatory Research and Gender Analysis. PBB Monograph No. 4. Online document. http://www.prgaprogram.org> Accessed [12/6/06].

Farrington, J. and Martin, A. (1988). Farmer participation in agricultural research: a review of concepts and recent practices. *Agricultural Administration Unit, Occasional Paper* No. 9. London: Overseas Development Institute.

Farrington, J. and Bebbington, A. (1993). *Reluctant partners: NGOs, the state and sustainable agricultural development*. London: Routledge.

Fortes, M. (1945). *The dynamics of clanship among the Tallensi: Being the first part of an analysis of the social structure of a Trans-Volta tribe*. London: Oxford University Press.

Friis-Hansen, E. (1999). Socio-economic dynamics of farmer management of local plant genetic resources: A framework for analysis with examples from a Tanzanian case study. *CDR Working Paper* 99, 3.

Friis-Hansen, E. (2000). Farmers' management and use of crop genetic diversity in Tanzania. In: Almekinders, C. J.M. and de Boef, W. (eds.) *Encouraging diversity: The conservation and development of plant genetic resources*. London: Intermediate Technology Publications, pp. 66-71.

Frölich, W. and Buah, S.S.J. (1991). Country report of Sorghum importance in Ghana. A paper presented at the Workshop of West and Central Africa Sorghum Research Network. March 8-15, 1991, Ougadougou, 11 pp.

Fukuda, W.M., Saad, G.N. and Lilja, N. (2005). Participatory cassava breeding in Northeast Brazil: Who adopts and why? PRGA Program Working Document No. 24. Online document. http://www.prgaprogram.org/modules/DownloadsPlus/uploads/PRGA_Publications/General/Working_Documents/Working_Document_No._24.pdf. Accessed [4/4/06].

Functowicz, S.O. and Ravetz, J.R. (1993). Science for the post-normal age. *Futures* 25(7): 739-755.

Ghana Statistical Service (2000). Ghana Living Standards Survey Report on the Fourth Round (GLSS 4). Accra: Ghana Statistical Service.

Ghana Statistical Service (2002). 2000 Population and housing census. Accra: Ghana Statistical Service.

Giampetro, M. (2003). *Multi-scale integrated analysis of agro-ecosystems*. Boca Raton, Florida: CRC Press, 437 pp.

Gibbon, D. (2002). Systems thinking, interdisciplinarity, and farmer participation: essential ingredients for working in more sustainable organic systems. In: Powell, J. (ed.) *UK Organic Research 2002*. Proceedings of the COR conference, 26-28 March 2002. Aberystwyth, pp. 105-108.

Glover, D.J. (1984). Contract farming and small holder outgrower schemes in less developed countries. *World Development* 12(11): 1143-57.

Glover, D.J. (1987). Increasing the benefits to small holders from contract farming: Problems for farmers' organisations and policy makers. *World Development* 15(4): 441-448.

Glover, D.J. (1994). Contract farming and commercialization of agriculture in developing countries. In: Von Braun, J. and Kennedy, E. (eds.) *Agricultural commercialization, economic development and nutrition.* Baltimore: John Hopkins University Press, pp. 166-175.

Glover, D. and Kusterer, K. (1990). *Small farmers, big business: Contract farming and Rural Development.* London: Macmillan.

Goldsmith, A. (1985). The private sector and rural development: Can agri-business help the small farmer? *World Development* 13(10): 1125-1138.

Gómez, F. and Smith, M.E. (1996). *Conservation and enhancement of maize with small farmers in Honduras*. A collaborative project between the Escuela Agricóla Panamericana (EAP) – Zamorano and the Cornel International Institute for Food, Agriculture and Development (CIIFAD). Project report. Ithaca, N.Y.: Cornell International Institute for Food, Agriculture and Development (mimeo).

Goodell, G. (1980). From status to contract: The significance of agrarian relations of production in West Japan and in Asiatic Persia. *Archives Européenes de Sociologie* 21(2): 285-325.

Greenwood, D.J. and Levin, M. (1998). *Introduction to action research: Social research for social change.* Thousand Oaks, CA: Sage Publications.

Grosh, B. (1994). Contract farming in Africa: An application of the new institutional economics. *Journal of African Economics* 3(2): 231-261.

Gustavsen, B. (2001). Theory and practice: The mediating discourse. In: Reason, P. and Bradbury, H. (eds.) *Handbook of action research: Participative inquiry and practice*. London: Sage Publications, pp. 17-26.

Handwerker, W.P. (1981). Productivity, marketing efficiency, and price-support programs: alternate paths to rural development in Liberia. *Human Organization* 40: 27-39.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R. (1997). *Coping with risk in agriculture*. Wallingford: CAB International.

Hardon, J.J. and De Boef, W.S. (1993). Linking farmers and plant breeders in local crop development. In: De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) *Cultivating knowledge: Genetic diversity, farmer experimentation and crop research*. London: Intermediate Technology Publications, pp. 64-71.

Harlan, J.R. (1992). *Crops and man*. 2nd ed. Madison: American Society of Agronomy and Crop Science Society of America.

Harlan, J.R. and De Wet, J.M.J. (1972). A simplified classification of cultivated sorghum. *Crop Science* 12(2): 172-176.

Harris, K.M. (1961). The sorghum midge (*Contarina sorghicola* Coq.) in Nigeria. *Bulletin of Entomological Research* 52: 129-146.

Heemskerk, W. (2004). Participatory approaches in agricultural research and development. Online document. http://knowledge.cta.int. Accessed [3/2/06].

Heron, J. and Reason, P. (2001). The practice of co-operative inquiry: Research with rather than on people. In: Reason, P. and Bradbury, H. (eds.) *Handbook of action research: Participative inquiry and practice*. London: Sage Publications, pp. 179-188.

Hounkonnou, D., Kossou, D.K., Kuyper, T.W., Leeuwis, C., Richards, P., Röling, N.G., Sakyi-Dawson, O. and Van Huis, A. (2006). Convergence of sciences: the management of agricultural research for small-scale farmers in Benin and Ghana. *NJAS-Wageningen Journal of Life Sciences* 53(3-4): 343-367.

House, L.R. (1985). *A guide to sorghum breeding*. 2nd Edition. Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics.

Howard, P. (2003). *Women and plants: Gender relations in biodiversity management* *and conservation*. London: ZED Books.

IBPGRI and ICRISAT (1993). *Descriptors for Sorghum* (*Sorghum bicolor* (L.) Moench). Rome, Italy: International Board for Plant Genetic Resources; Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics.

ICRISAT (1991). ICRISAT West and Central African Programs Annual report 1990. Niamey, Niger: ICRISAT.

IFAD (1990). Ghana: Upper East Region land conservation and small holder rehabilitation project. International Fund for Agricultural Development, Rome. Report No. 0244-GH, Vol. 1.

IFAD (2006). Republic of Ghana. Upper East land conservation and small holder rehabilitation Project. LACOSCREP Phase II. Interim Evaluation Report No 1757-GH, 103 pp.

IFAD/ICRISAT/FRI/SARI/ARI (1999). Increasing sorghum productivity in Ghana. Final PRA Report on sorghum production, processing, utilization, marketing systems in selected areas in Northern Ghana, 61 pp.

ISTA (1999). *International rules for seed testing*. Zurich: ISTA.

Jarvis, D.I., Meyer, L. Klemick, H. Guarino, L., Smale, M., Brown, A.H.D. Sadiki, M., Sthapit, H. and Hodgkin, T. (2000a). *A training guide for in situ conservation on-farm*. Version 1. Rome: IPGRI.

Jarvis, D.I., Sthapit, B. and Sears, L. (eds.) (2000b). *Conserving agricultural biodiversity in situ: A scientific basis for sustainable agriculture*. Proceedings of an IPGRI Workshop, Pokhara, Nepal, 5–12 July, 1999.

Jarvis, D.I., Zoes, V. and Hodgkin, T. (2004). On-farm management of crop genetic diversity and the convention on biological diversity programme of work on agricultural biodiversity. *PGR Newsletter* 138: 5-17.

Jatoe, J.D.B. (2000). *Determinants of adoption and impact of improved sorghum varieties in the Upper West Region of Ghana*. MPhil. thesis, University of Ghana, Legon, 102 pp.

Jatoe, J.D.B., Al-hassan, R.M. and Abatania, L.N. (2005). Factors affecting the adoption of improved sorghum varieties among farming households in North-west Ghana: A probit analysis. *Ghana Journal of Development Studies* 2 (1): 37-50.

Jiggins, J. and Gibbon, D. (1997). What does inter-disciplinarity mean? Paper presented at the 13th European Seminar on Extension Education. 1–6 September 1997. Dublin, 13 pp.

Jusu, M. (1999). *Management of genetic variability in rice* (*Oryza sativa* L. and *O. glaberrima* Steud.) *by breeders and farmers in Sierra Leone*. PhD thesis, Wageningen University, Wageningen, 198 pp.

Karp, A., Kresovich, S., Bhat, K.V. Ayad, W.G. and Hodgkin, T. (1997). *Molecular* *tools in plant genetic resources conservation: A guide to the technology*. IBGRI Technical bulletin No 2, Rome: IBGRI

Kebede, K. (1991). The role of Ethiopian germplasm resources in the national breeding program. In: Engles, J.M., Hawkes, J.G. and Worede, M. (eds.) *Plant genetic resources of Ethiopia*. Cambridge: Cambridge University Press, pp. 315-322.

Killough, S. (2005). Participatory approaches to agricultural research and extension. In: Gonsalves, J., Becker, T., Braun, A., Campilan, D., De Chavez, H., Fajber, E., Kapiriri, M., Rivaca-Caminde, J. and Vernooy, R. (eds.) *Participatory research and development for sustainable agriculture and natural resource management: A sourcebook*. Vol. 1, pp. 27-38.

Kirsten, J. and Sartorious, K. (2002). Linking agribusiness and small-scale farmers in developing countries: Is there a new role for contract farming? *Development Southern Africa* 19(4): 503-529.

Kudadjie, C.Y., Struik, P.C., Richards, P. and Offei, S.K. (2004). Assessing production constraints, management and use of sorghum diversity in north-east Ghana: A diagnostic study. *NJAS – Wageningen Journal of Life Sciences* 52, 371-391.

Kudadjie, C.Y., Struik, P.C., Richards, P., Offei, S.K. and Atengdem, P. (2006) Understanding variation in sorghum through with-farmer experimentation. *IJAS – International Journal of Agricultural Sustainability*. (in press)

Lambert, D.H. (1985). *Swamp rice farming*. Boulder, Co: Westview.

Lando, R.P. and Mak, S. (1994). Cambodian farmers decision making in the choice of traditional rainfed lowland rice varieties. *IRRI Research Paper Series* 154, Los Baños: IRRI.

Larinde, M. (1997). Seed security: an achievable goal or a mirage? Paper presented at the International workshop on seed security for food security in developing countries 30 Nov–1 Dec 1997, Florence, 5 pp.

Last, M. (2000). Social Exclusion in Northern Nigeria. In: Hubert, J. (ed.) *Madness, disability and social exclusion.* London: Routledge, pp. 217-239.

Lave, J. (1985). The values of quantification. In: Law, J. (ed.) *Power, action and knowledge: A new sociology of knowledge*. London: Routledge, pp. 88-111.

Lee, M. (1995). DNA markers and plant breeding programmes. *Advances in Agronomy* 55: 265-344.

Leeuwis, C. and Van den Ban, A. (2004). *Communication for rural innovation: Rethinking agricultural extension.* (3rd Edition) Oxford: Blackwell Science.

Linnares, O. (1992). *Power, prayer and production: The Jola of Casamance*. New York: Cambridge Publishers.

Lipton, M. and Longhurst, R. (1989). *New seeds and poor people*. London: Unwin and

Hyman.

Little, P.D. and Watts, M.J. (1994). Introduction. In: Little, P.D. and Watts, M.J. (eds.) *Living under contract: Contract farming and agrarian transformation in Sub-Saharan Africa*. Madison: University of Winconsin Press, pp. 3-18.

Longley, C. (1999). On-farm rice variability and change in Sierra Leone: Farmers' perceptions of semi-weed types. *ODI Network Paper* 96: 10-14.

Longley, C.A. (2000). *A social life of seeds: Local management of crop variability in north-west Sierra Leone*. PhD thesis, Department of Anthropology, University College, London.

Longley, C. and Richards, P. (1993). Selection strategies of rice farmers in Sierra Leone. In: De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) *Cultivating knowledge: Genetic diversity, farmer experimentation and crop research*. Intermediate Technology Publications: London, pp. 51-57.

Longley, C. and Richards, P. (1999). Farmer seed systems and the effects of disaster. Paper presented at the international workshop on developing institutional agreements and capacity to assist farmers in disaster situations to restore agricultural systems and seed security activities, Rome, Italy, 3-5 November, 1998. Online document. http://www.fao.org/waicent/faoinfo/agricult/agp/agps/Norway/paper3.htm. Accessed [2-5-2002].

Louette, D and Smale, M. (1998). Farmers' seed selection practices and maize variety characteristics in a traditionally-based Mexican community. *Economics Working Paper* 98-04. Mexico, D.F.: CIMMYT.

Louette, D., Charrier, A. and Berthaud, J. (1997). *In situ* conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. *Economic Botany* 51: 20-28.

Louwaars, N.P. (1996). Seed legislation in developing countries; possibilities and pitfalls for seed system development. In: Van Amstem, H., Bottema, J.W.T., Sidik, M. and Van Santen, C.E. (eds.) *Integrating seed systems for annual food crops.* Proceedings of a workshop, 24–27 Oct 1995, Malang, Indonesia, pp. 77-81.

Lyon, F. and Afikorah-Danquah, S. (1998). Small-scale seed provision in Ghana: social relations, contracts and institutions for micro-enterprise development. *Agricultural Research and Extension Network Paper No*. 84, ODI, London.

Maiti, R.J., Raju, P.S. and Bindinger, R.R. (1985). Studies on germinability and some aspects of pre-harvest physiology of sorghum grain. *Seed Science and Technol*ogy 13: 27-35.

Manful, J.T., Atokple, I.D.K. and Gayin, J. (2001). Evaluation of agronomic and nutritional characteristics of released/recommended sorghum varieties in Ghana. In: Akintayo, I. and Sedgo, J. (eds.) *Towards sustainable sorghum production,* *utilization and commercialization in West and Central Africa*. Proceedings of a Technical workshop of the West and Central Africa Sorghum Resources Network, Lome, Togo, 19–22 April. Mali: WCASRN, pp. 60-66.

McFarlane, J. (1989). The hemipterous insects and spiders of sorghum in Northern Nigeria. *Insect Science and its Application* 10: 277-284.

McGuire, S. 2002. Farmers' views and management of sorghum diversity in Western Harerghe, Ethiopia: Implications for collaboration with formal breeding. In: Cleveland, D. and Soleri, D. (eds.) *Farmers, scientists and plant breeding: Integrating knowledge and practice*. Wallingford, Oxon: CABI, pp. 107-136.

McGuire , S.J. (2005). *Getting genes: Rethinking seed system analysis and reform for sorghum in Ethiopia.* PhD thesis, Wageningen University, Wageningen, 279 pp.

McGuire, S.J., Manicad, G. and Sperling, L. (1999). *Technical and institutional issues in participatory plant breeding – done from a perspective of farmer plant breeding: A global analysis of issues and of current experience.* Cali, Colombia: CIAT. CGIAR Systemwide Program on Participatory Research and Gender Analysis, PPB Monograph No. 2, 89 pp.

McGuire, S.J., Manicad, G. and Sperling, L. (2003). *Technical and institutional issues in participatory plant breeding – done from the perspective of farmer plant breeding: A global analysis of issues, and of current experience.* Cali, Colombia: CGIAR Systemwide Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation; Centro Internationale de Agricultura Tropicale. PBB Monograph No. 2, 124 pp.

Mighell, R. and Jones, M. (1963). *Vertical co-ordination and contract farming*. Washington, D.C.: USDA.

Millar, D. (1993). Farmer experimentation and the cosmovision paradigm. In: De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) *Cultivating knowl-edge: Genetic diversity, farmer experimentation and crop research*. London: Intermediate Technology Publications, pp. 44-50.

Millar, D., Aniah, R. and Atoyure, P. (1999). Shrines and groves. *Compas Magazine for endogenous development*. October Issue No. 2: 34-36.

Mortimore, M. (1989). *Adapting to drought: Farmers, famines and desertification in West Africa*. Cambridge: Cambridge University Press.

Mukuru, S.Z. (1993). Sorghum and millet in eastern Africa. In: Byth, D.E. (ed.) *Sorghum and millets commodity and research environments*. India: ICRISAT.

Murty, D.S., Nwasike, C.C. and Atokple, I.D.K. (1998). Registration of 'ICSV 111' Sorghum Cultivar. *Crop Science* 38: 1716-1717.

Musa, T.M. (1999). Farmer seed systems. Paper presented at the international workshop on developing institutional agreements and capacity to assist farmers in disaster situations to restore agricultural systems and seed security activities, Rome, Italy, 3-5 November, 1998. Rome: FAO, 13 pp.

NAES (1984). Annual Report 1983/84. Nyankpala Agricultural Experimental Station. Tamale, Ghana.

Ndjeuna, J. (2002). Local village seed systems and pearl millet seed quality in Niger. *Experimental Agriculture* 38: 149-162.

Netting, R. (1974). Agrarian ecology. *Annual review of Anthropology* 3: 21-56.

Nuijten, E. (2005). *Farmer management of gene flow: The impact of gender and breeding system on genetic diversity and crop improvement in The Gambia*. PhD thesis, Wageningen University, Wageningen, 270 pp.

O'Laughlin, M.B. (1973). *Mbum beer-parties: Structure of production and exchange in an African social formation.* PhD thesis, Yale University.

Ollitreault, P. (1987). *Evaluation génétique des sorghos cultivés (Sorghum bicolor (L.) Moench) par l'analyse conjointe de diversités enzymatiques et morpho-physiologiques: Relation avec les sorghos sauvages*. PhD thesis, Faculté des Science Université Paris – XII, Orsay, 187 pp.

Offei, S.K., Sakyi-Dawson, O. and Nyaku, T. (2002). *Technography of sorghum in Ghana*. Report presented at 'Convergence of Sciences' International Workshop, 23-29 March, Cotonou, 46 pp. (Unpublished report).

Okali, C., Sumberg, J. and Farrington, J. (1994). *Farmer participatory research: Rhetoric and reality.* London: Intermediate Technology Publications, 159 pp.

Padmanabhan, M.A. (2002). *Trying to grow: Gender relations and agricultural innovations in Northern Ghana.* Munster: LiT, 255 pp.

Pallier, G. (1972). Les dolotières de Ouagadougou (Haute-Volta). *Travaux et Documents de Géographie Tropicale* 7: 120-139.

Pedersen, J.F., Toy, J.J., and Johnson, B. (1998). Natural outcrossing of sorghum and sudangrass in the Central Great Plains. *Crop Science* 38: 937-939.

Pejic, I., Ajmone-Marsan, P., Morgante, M., Kozumplick, V., Castiglioni, P., Taramino, G. and Motto, M. (1998). Comparative analysis of genetic similarity among maize inbred lines detected by RFLPs, RAPDs, SSRs, and AFLPs. *Theoretical and Applied Genetics* 97: 1248-1255.

Porter, G. and Phillips-Howard, K. (1997). Outgrower barley cultivation in the Jos Plateau, Nigeria: A case study of agricultural innovation. *Geographical Journal* 160(3): 319-327.

Prain, G., Fujisaka, S., and Warren, M. (eds.) (1999). *Biological and cultural diversity: The role of indigenous agricultural experimentation in development.* London: Intermediate Technology Publications.

Prasado Rao, K.E., Mengesha, M.H. and Reddy, V.G. (1989). International use of a sorghum germplasm collection. In: Brown, A.H.D., Marshall, D.R., Frankel, O.H. and Williams, T.J. (eds.) *The use of plant genetic resources*. Cambridge: Cambridge University Press, pp. 49-67.

Pretty, J.N., Guijt, I., Thompson, J. and Scoones, I. (1995). *A trainers' guide for participatory learning and action*. IIED, London, UK.

Quaye, W. (2001). *Sorghum market integration and demand for sorghum in Ghana*. MPhil. Thesis. University of Ghana, Legon, 100 pp.

Ratnadass, A. and Ajayi, O. (1995). Panicle insect pests of sorghum in West Africa. In: Nwanze, K.F. and Youm, O. (eds.) *Panicle insect pests of sorghum and pearl millet*. Proc. International Consultative Workshop, 4–7, Oct 1993. Niamey: ICRISAT, pp. 29-38.

Ratnadass, A., Cissé, B. and Mallé, K. (1994a). Notes on the biology and immature stages of West African sorghum head bugs *Eurystylus immaculatus* and *Creontiades pallidus* (Heteroptera: Miridae). *Bulletin of Entomological Research* 84: 383-388.

Ratnadass, A., Ramaiah, K.V., Sharma, H.C. and Cissé, B. (1994b). Réaction de variétés de sorgho aux attaques de la punaise des panicules *Eurystylus Odhiambo* (Heteroptera, Miridae) en Afrique de L'Ouest. In: Menyonga, J.M., Bezuneh, T., Yayock and Soumana, I. (eds.) *Progress in food grain research and production in semi-arid Africa*. Proceedings of the SAFGRAD Inter-Network Conference, 7–14 Mar, 1991, Niamey. Ougadougou: SAFGRAD, pp. 333-343.

Rattray, R S. (1932). *Tribes of the Ashanti Hinterland*. Vol. II. Oxford: The Clarendon Press.

Reason, P. and Bradbury, H. (2001). Introduction: Inquiry and participation in search of a world worthy of human aspiration. In: Reason, P. and Bradbury, H. (eds.) *Handbook of action research: Participative inquiry and practice.* London: Sage Publications, pp. 1-14.

Reij, C. and Waters-Bayer, A. (eds.) (2001). *Farmer innovation in Africa: A source of inspiration for agricultural development*. London: Earthscan, 384 pp.

Rhoades, R.E. and Bebbington, A. (1991). Farmers as experimenters. In: Haverkort, B., Van de Kamp, J. and Waters-Bayer, A. (eds.) *Joining farmers' experiments*.: Experiences in participatory technology development. London: Intermediate Technology Publications, pp. 251-253.

Rice, E., Smale, M and Blanco, J.L. (1998). Farmers' use of improved seed selection practices in Mexican maize: Evidence and issues from the Sierra de Santa Marta. *World Development* 26(9): 1625-1640.

Richards, P. (1985). *Indigenous agricultural revolution*. Hutchinson, Londres and Westview Press, Boulder, Colorado.

Richards, P. (1986). *Coping with hunger: Hazard and experiment in an African rice farming system*. London: Unwin.

Richards, P. (1995). Farmer knowledge and plant genetic resource management. In: Engels, J.M.M. (ed.) *In situ conservation and sustainable plant genetic resources for food and agriculture in developing countries*. Report of a DSE/ATSAF/IFPRI workshop, 2–4 May 1995, Bonn-Röttgen. Feldafing: A joint publication of IPGR, Rome and DSE, pp. 52-58.

Richards, P. (1997). Towards an African Green Revolution? An anthropology of rice research in Sierra Leone. In: Nyerges, A.E. (ed.) *Ecology of practice: Studies in food crop production in Sub-Saharan Africa.* London: Gordon and Breach, pp. 201-252.

Richards, P. (2001). Technography: Notes and methods. Convergence of Sciences Project. Wageningen University, Wageningen. Unpublished document, 9 pp.

Richards, P. (2003) Technology and development: Convergence and scaling up. Convergence of Sciences Project, Wageningen University. Unpublished document. 12 pp.

Rijal, D., Rana, R., Subedi, A. And Sthapit, B. (2000). Adding value to landraces: Community-based approaches for in situ conservation of plant genetic resources in Nepal. In: Friis-Hansen, E. and Sthapit, B. (eds.) *Participatory approaches to the conservation and use of plant genetic resource.* Rome: IPGRI, pp. 166-172.

Rohrbach, D. and Tripp, R. (2001). Policies for African seed enterprise development. *Food Policy* 27(2): 147-161.

Röling, N.G. (1996). Towards an interactive science. *European Journal of Agricultural Education and Extension* 2: 35-48.

Röling, N.G., Hounkonnou, Offei, S.K., Tossou, R. and Van Huis, A. (2004). Linking Science and farmers' innovative capacity: Diagnostic studies from Ghana and Benin. *NJAS–Wageningen Journal of Life Sciences* 52: 211-235.

Rosenow, D.T. (2002). West Africa-Western region host country programme enhancement. International Sorghum and Millet Collaborative Research Support Programme. Online document. http://www.intsormil.org. Accessed [4/4/06].

Rottger, A. (2004). Strengthening farm-agri-business linkages in Africa: Summary results of five country studies in Ghana, Nigeria, Kenya, Uganda and South Africa. AGSF Occasional Paper 6. FAO, Rome.

Roy, E.P. (1972). *Contract farming and economic integration*. Danville. III. Interstate Press.

Runsten, D. and Key, N. (1996). Contract farming in Developing Countries: theoretical aspects and analysis of some Mexican cases. Research Report No. 3. August 1996. Report prepared for the United Nations Economic Commission for

Latin America and the Caribbean, Santiago, Chile.

Saad, N. (2002). Farmer processes of experimentation and innovation: A review of the literature. Working Document. CGIAR Systemwide Program on Participatory Research and Gender Analysis. Online document. http://www.prgaprogram.org/ modules/DownloadsPlus/uploads/ PRGA_ Publications/General working documents/ wd21.pdf. Accessed [7/11/05]

Saad, N., Hernández, L.A. and Morante, N. (2001). Complementing farmers' genetic knowledge: Farmer breeding workshop in Turipaná, Colombia. CIAT-IPRA, CORPOICA, DFID, PRGA. Online document. http://www.prgaprogram.org/ modules/DownloadsPlus/uploads/PRGA_Publications/Plant_Breeding. Accessed [5/5/06].

Salazar, R. (2002). Some lessons in adapting the IPM-FFS approach to Participatory plant breeding in Rice. Paper presented at the International Learning Workshop on Farmer Field Schools: Emerging issues and challenges, Yogyarkarta, Indonesia 21–25 October 2002, 9 pp.

Saul, M. (1981). Beer, sorghum and women: production for the market in rural Upper Volta. *Africa* 51(3): 746-764.

Saul, M. (1983). Work parties, wages and accumulation in a Voltaic Village. *American Ethnologist* 10(1): 77-96.

Saul, M. (1987). The organization of a West African grain market. *American Anthropologist* 89(1): 74-95.

Scarborough, V. (ed.) (1996). *Farmer-led approaches to extension*. Papers presented at a workshop in the Philippines, July 1995. ODI Network Papers 59 a, b, c. London: Agricultural Research & Extension Network, Overseas Development Institute.

Schipprack, W. and Mercer-Quarshie, H. (1984). Sorghum production and improvement in Ghana. Paper presented at the regional workshop on Sorghum Improvement in West Africa, Ouagadougou, 27–30, November, 1984, 28 pp.

Scoones, I. and Thompson, J. (1994). Introduction. In: Scoones, I. and Thompson, J. (eds.) *Beyond farmer first: Rural people's knowledge, agricultural research and extension practice*s. Intermediate Technology Publications, International Institute for Environmental Development, pp. 1-12.

Sharma, H.C., Doumbia, M. Haidara, M., Scheruing, J.F., Ramaiah, K.V. and Beninati, N.F. (1994). Sources and mechanisms of resistance to head bug, *Eurustylus immaculatus* Odh. in West Africa. *Insect Science and its Application* 15: 39-48.

Sharma, H.C., Doumbia, M. and Diorisso, N.Y. (1992). A head cage technique to screen sorghum for resistance to mirid head bug *Eurystylus immaculatus* Odh. in

West Africa. *Insect Science and its Application* 13: 417-427.

Smale, M., Aguirre, A., Bellon, M., Mendoza, J. and Rosas, I.M. (1999a) Farmer management of maize diversity in the central valleys of Oaxaca, Mexico. CIMMYT *Economics working paper* 99-09. Mexico D.F.: CIMMYT.

Smale, M., Bellon, M. and Aguirre, J.A.A. (1999b). The private and public characteristics of maize landraces and the area allocation decisions of farmers in a center of crop diversity. *CIMMYT Economics Working Pape*r 99-08. Mexico, D.F.: CIMMYT.

Sofranko, A. Frerichs, R, Samy, M. and Swanson, B. (2000). Will farmers organize? Structural change and loss of control over production. Online document. http//web.aces.uuiuc.edu/value/research/organize.htm. Accessed [21/5/06].

Soleri, D. and Cleveland, D.A. (2001). Farmers' genetic perceptions regarding their crop populations: an example with maize in the central valleys of Oaxaca, Mexico. *Economic Botany* 55: 106-128.

Soleri, S., Cleveland, D.A. and Smith, S.E. (1999) Creating common ground in collaborative crop improvement. *ILEIA Newsletter* (December issue): 20-22.

Song, Y. and Jiggins, J. (2003). Women and maize breeding: The development of new seed systems in a marginal area in south-west China. In: Howard, P. (ed), *Women and Plants: Gender relations in biodiversity management and conservation.* London: Zed Press and Palgrave-MacMillan, pp. 273-288.

Sperling, L. and Loevinsohn, M.E. (1993). The dynamics of adoption: Distribution and mortality of bean varieties among small farmers in Rwanda. *Agricultural Systems* 41: 441-453.

Sperling, L. and Loevinsohn, M.E. (eds.) (1996). *Using diversity: Enhancing and maintaining genetic resources on-farm*. New Dehli: IDRC.

Sperling, L. and Scheidegger, U. (1996). Results, methods and issues in participatory selection: The case of beans in Rwanda. *Gatekeeper* Series no. 51. London: IIED.

Sperling, L., Loevinsohn, M. and Ntabomvura, B. (1993). Rethinking farmers' role in plant breeding: Local bean experts and on-station selection in Rwanda. *Experimental Agriculture* 29: 509-519.

Sperling, L., Remington, T., Jon Haugen, M. and Nagoda, S. (eds.) (2004). Addressing seed security in disaster response: Linking relief with development, overview. Cali, Colombia: International Centre for Tropical Agriculture. Online document. http://www.ciat.cgiar.org/africa/seeds.htm. Accessed [22-4-06].

Sporleder, T.L. (1992). Managerial Economics of vertically coordinated firms. *American Journal of Agricultural Economics* 74: 1226-1230.

SRID (2004). *Facts and figures*. Statistics, Research and Information. Department-Ministry of Food and Agriculture, Ghana, 38 pp.

Tanzubil, P.B. (1993). African armyworm in Ghana: control problems and prospects. In: Improvement of Cropping systems in the savanna zone: The challenges ahead. Proceedings of the 3rd Workshop on Improving Farming systems in the Interior Savanna Zone of Ghana. 27-29 April, 1993. Nyankpala, Ghana, pp. 208-214.

Tanzubil, P.B., Zakariah, M. and Alem, A. (2005). Population ecology and damage potential of mired bugs infesting sorghum panicles in Northern Ghana. *Tropical Science* 35(2): 58-62.

Taramino, G., Tarchini, R., Ferrario, S., Lee, M. and Pé, M.E. (1997). Characterization and mapping of Simple Sequence Repeats (SSRs) in *Sorghum bicolor*. *Theoretical and Applied Genetics* 98: 171-177.

Teetes, G.L. and Pendleton, B.B. (2001). Insect pests of sorghum. In: Smith, C.W. and Frederiksen, R.A. (eds.) *Sorghum: Origin, history, technology, and production.* New York: John Wiley, pp. 443-495.

Terborbri, P., Gyasi, K.O., Abatania, L.N. and Atokple, I.D.K. (2000). Adoption of improved sorghum varieties in the Guinea Savannah zone of Ghana. Unpublished technical report prepared for SARI, Ghana, 21 pp.

Teshome, A. (2001). Spatio-temporal dynamics of crop genetic diversity and farmers' seed selection *in situ*, Ethiopia. Online document. http://www.idrc.ca/en/ev-30035-201-1-DO_TOPIC.html. Accessed [7-5-06].

Teshome, A., Fahrig, L., Torrance, J.K., Lambert, J.D., Anason, T.J. and Baum, B.R. (1999). Maintenance of sorghum (*Sorghum bicolor*, Poaceae) landrace diversity by farmers' selection in Ethiopia. *Economic Botany* 53(1): 79-88.

Thijssen, R. (2003). PTD practitioners: Back to school? *LEISA Magazine* (March) pp. 7.

Tiruneh, A. (2001). Socio-economic and gender issues in the selection, conservation and utilization of sorghum landraces in Ethiopia. Online document. http://www.idrc.ca/uploads/user-S/10928613081gender.doc. Accessed [26-6-06].

Tress, B., Tress, G. and Van der Valk, A. (2003) Interdisciplinarity and trans-disciplinarity in landscape studies: The Wageningen Delta Approach. In: Tress, B., Tress, G., Van der Valk, A. and Fry, G. (eds.) *Interdisciplinary and trans-disciplinary landscape studies: Potential and limitations*. Wageningen University, Wageningen, pp. 8-17.

Tripp, R., Marfo, A., Dankyi, A. and Read, M. (1987). *Changing maize production practices of small-scale farmers in the Wenchi Region, Ghana*. Ghana Grains Development Project. Mexico, D.F.: CIMMYT.

Van de Fliert, E. (1993). *Integrated pest management. Farmer field schools generate sustainable practices: A case study in Central Java evaluating IPM training*. PhD thesis, Wageningen Agricultural University, Wageningen.

Van der Burg, J. (1999). Sustainable seed security: The need for a differential seed technology research and development approach. Proceedings of the regional technical meeting on seed policy and programmes for sub-saharan Africa, Abidjan, Cote d'Ivoire, 23-27 Nov 1998. Online document. http://www.fao.org/ag/AGP/AGOS/abidjan/ paper13.htm. Accessed [4/11/04].

Van Dusseldorp, D. and Box, L. (1993). Local and scientific knowledge: Developing a dialogue. In: De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) *Cultivating knowledge: Genetic diversity, farmer experimentation and crop research*. London: Intermediate Technology Publications, pp. 20-26.

Van Gastel, T.J.G., Gregg, B.R. and Asiedu, E.A. (2002). Seed quality control in developing countries. *Journal of New Seeds* 4: 117-130.

Van Hintum, T.L.J. (1994). *Drowning in the genepool: Managing genetic diversity in genebank collections*. PhD thesis, Department of Plant Breeding Research, Swedish University of Agricultural Sciences, Svalöv, Sweden.

Van Oosterhout, S. (1993). Sorghum genetic resources of small scale farmers in Zimbabwe. In: De Boef, W., Amanor, K., Wellard, K. and Bebbington, A. (eds.) *Cultivating knowledge: Genetic diversity, farmer experimentation and crop research*. London: Intermediate Technology Publications, pp. 89-95.

Van Schoubroek, F. (1999). *Learning to fight a fly: Developing citrus IPM in Bhutan*. PhD thesis, Wageningen Agricultural University, Wageningen, 200 pp.

Vellema, S. (2002). *Making contract farming work? Society and technology in Philippine transnational agribusiness*. Maastricht: Shaker Publishing.

Vissoh, P., Gbehounou, G., Ahanchede, A., Kuyper, T.W. and Röling, N.G. (2004). Weeds as agricultural constraints to farmers in Benin: results of a diagnostic study. *NJAS-Wageningen Journal of Life Sciences* 52: 305-330.

Walker, D.J. and Tripp, R. (1997). Seed management by small-scale farmers in Ghana and Zambia. In: *International workshop on seed security for food security*. 30 Nov-1 Dec 1997, Florence, Italy. FAO, Rome, Italy, pp. 207-215.

Watts, M.J. (1994). Life under contract: Contract farming, agrarian restructuring and flexible accumulation. In: Little, P.D. and Watts, M.J. (eds.) *Living under contract: Contract farming and agrarian transformation in Sub-Saharan Africa*. Madison: University of Wisconsin Press, pp. 21-77.

Webber, P. (1990). *Ecological energetics in the West African Savanna: The flow of energy in a smallholder farming community in Kusasi, north-east Ghana*. Unpublished PhD thesis, Centre of West African Studies, University of Birmingham.

Webber, P. (1996). Agrarian change in Kusasi, North-East Ghana. *Africa* 66(3): 437-457.

Weil, P. (1986). Agricultural Intensification and Fertility in the Gambia (West Africa). In: Handwerker, W.P. (ed), *Culture and reproduction: An anthropological critique*

of demographic transition theory. Westview: Boulder, Co, pp. 294-320.
Welhausen, E.J., Roberts, L.M. and Hernandez, E.X. (1952). *Races of maize in Mexico: Their origin, characteristics and distribution.* The Bussey Institution. Cambridge: Harvard University.
Weltzien, E. and Von Brocke, K. (2000). Seed systems and their potential for innovation: Conceptual framework for analysis. In: Sperling, L. (ed.) *Targetted seed aid and seed aid and seed-system interventions: Strengthening small-farmer seed systems in East and Central Africa*. Kampala, Uganda, 21-24 June 2000. Online document. http://www.prgaprogram.org/modules/DownloadsPlus/ uploads/ PRGA_ Publications/uganda_seed_procs.pdf. Accessed [3/6/06].
Weltzien, E., Whitaker, M.L. and Anders, M.M. (1996). Farmer participation in pearl millet breeding for marginal environments. In: Eyzaguirre, P. and Iwanaga, M. (eds.) *Participatory plant breeding*. Proceedings of a Workshop on participatory plant breeding. Wageningen, 26-29 July 1995. Rome: IPGRI, pp. 128-143.
Weltzien, E., Smith, M.E., Meitzner, L.S. and Sperling, L. (2000). *Technical and institutional issues in participatory plant breeding - From the perspective of formal plant breeding: A global analysis of issues, results, and current experience.* CGIAR Systemwide Program on Participatory Research and Gender Analysis for Technology development and Institutional Innovation. PBB Monograph No. 1. Online document. http://www.prgaprogram.org/modules/modules/downloadsplus/ uploads/PRGA Publications/Plant_Breeding/Working documents/wd3.pdf. Accessed [2/3/02].
Whitehead, A. (1981). 'I'm Hungry Mum': The politics of domestic budgeting in North East Ghana. In: Young, K., Wolkovitz, C. and McCullugh, R. (eds.) *Of marriage and the market*. London: CSE Books.
Whitehead, A. (2002). Tracking livelihood change: Theoretical, methodological and empirical perspectives from north-east Ghana. *Journal of Southern African Studies* 28(3): 575-598.
Whitehead, A. (2006). Persistent poverty in north-east Ghana. *Journal of Development Studies* 42(2): 278-300.
Wilson, D.O. (1995). The storage of orthodox seeds. In: Basra, A.S. (ed.) *Seed quality: Basic mechanisms and agricultural implications*. New York: The Haworth Press, pp. 173-200.
Woldeselassie, Y.S. (1999). *Evaluation of status and quality of barley seed used by the northern and central Ethiopian farmers*. MSc thesis, University of Jordan, Amman, Jordan, 65 pp.
Wood, D. and Lenné, J.M. (1997). The conservation of agrobiodiversity on-farm: Questioning the emerging paradigm. *Biodiversity and Conservation* 6(1): 109-129.

World Bank (1989). *Sub-Saharan Africa: From crisis to sustainable growth.* Washington DC: World Bank.

Wright, M. and Tyler, P. (1994). *Traditional seed saving practices in Northern Ghana and central Malawi*. NRI, ODA, Chatham, UK, 55 pp.

Wright, M., Delimini, L., Luhanga, J., Mushi, C. and Tisini, H. (1995). *The quality of farmer saved seed in Ghana, Malawi and Tanzania*. NRI, ODA, Chatham UK, 34 pp.

Zimmerer, K.S. (1991). Labour shortages and crop diversity in the southern Peruvian Sierra. *Geographical Review* 81(4): 414-432.

Summary

Over the past few decades there has been growing concern that small-scale farmers in sub-Saharan Africa (SSA) have derived sub-optimal benefits from agricultural research. A key area for concern about the ineffectiveness of research is crop improvement. Two main reasons why formal improvement has achieved little for farmers in SSA are thought to be (i) agro-ecological complexities and (ii) the failure to produce varieties addressing farmers' needs.

Increasingly, it has been argued that sub-optimal research impact, especially in Africa where problems are diverse, is connected to lack of farmer involvement and that increased participation might help research to become better focused and research results to be more rapidly adopted. In response, efforts have been made in the recent past to develop farmer participatory approaches that attempt actively to involve farmers in setting the research agenda, and in planning and prioritizing technological needs. However, linking researchers and farmers effectively in research is not easy. Prevailing conditions make it difficult for farmers fully to appropriate technologies generated from agricultural research. Even though African farmers are often very innovative, technology development takes place within a wide institutional context and policy framework over which farmers have little control. Other societal stakeholders also influence the agricultural innovation process. This leaves farmers with small windows of opportunity through which agricultural research can make a useful contribution. The challenge, then, is for researchers to understand the contexts in which farmers find themselves, to identify and target these windows of opportunity, and to make informed strategic choices about what type of research to invest in. This calls for a different way of organizing research whereby agricultural innovation is recognized as a multi-stakeholder process involving research institutions and other important societal stakeholders (including farmers), and in which attention is paid to developing wider interactive relations among these stakeholders. There is no agreed way, however, to go about this task.

Convergence of Sciences (CoS) suggests an approach to conducting this alternative form of research in which agricultural innovation is recognized and organized as a multi-stakeholder process. The underlying principles of the CoS approach are trans-disciplinarity and inter-disciplinarity. Inter-disciplinarity and trans-disciplinarity are two essential elements in which (1) the social and natural sciences work together to contribute to problem solving within a given context, and to create new knowledge or modes of thinking; and (2) integration is sought between different stakeholders, including academic researchers, farmers and other user-group participants, all seeking

a common research goal. Technographic studies and diagnostic studies are two main tools developed by CoS for making informed strategic choices about the type of research to invest in. A technographic study, as a first step in problem identification, explores the innovation landscape for an identified sector by looking at technological histories, institutions and stakeholders within a given context. A diagnostic study becomes the second step in problem identification to define the research problem and ensure that the research is anchored in the needs and opportunities of farmers.

This thesis explores ways of conducting agricultural research using the CoS approach within the context of sorghum diversity management and variety maintenance, sorghum genetic diversity, seed management and sorghum production under small-farmer oriented but increasingly market-driven conditions in north-east Ghana. The choice of sorghum is based on a technographic study (not covered in this thesis) carried out in Ghana between January and March 2002. The technographic study revealed sorghum to be a somewhat neglected 'grass roots' crop largely grown by small-scale farmers. Until recently low priority has been given to the crop, and it has received little attention from national research institutions. The importance of sorghum for farmers and the budding interest of the private sector in sorghum (for brewing) underscored the need to pay closer attention to the crop.

Concerns about the sub-optimal impact of research for small-scale farmers in Africa, and the call for alternative pathways by which science can make a more useful contribution to farmers' livelihoods suggests that the knowledge and research capacities of farmers should be included in future efforts. This thesis is an attempt to explore what might be possible in this regard, with a focus on sorghum. The study seeks to situate science and farmer initiative within the context of sorghum genetic resource management and aims at answering two main questions:

- How and in what area(s) can farmers and scientists effectively engage in agricultural research towards a sustainable use and management of sorghum genetic resource management in Ghana?
- What lessons does the CoS approach provide for future efforts in designing and conducting research that is relevant for the conditions of small farmers?

To answer these questions it was important to first determine the type of research that would be considered useful for farmers by assessing farmer constraints, needs, strategies, knowledge level and skills in using and managing sorghum genetic resources. Following a diagnostic study four specific objectives were established for the research:

- To determine how farmers use and manage their sorghum varieties and the factors influencing this management.
- To determine the genetic diversity of sorghum varieties, as managed by farmers.

- To determine farmers' knowledge and practices with regard to seed storage and diversity management, with a view to possible strengthening of local capacity for variety maintenance and production of quality seed.
- To explore how new relationships could be created and sustained between researchers, farmers and the private sector under market-driven conditions for sorghum production.

The thesis is divided into eight main chapters.

Chapter 1 provides an introduction to the research and the problems to be addressed, and offers an overview of chapter contents.

Using a diagnostic study approach Chapter 2 provides a contextual overview based on technography. Within the prevailing cropping system sorghum was found to be a salient crop (apparently losing importance to maize), and forming an integral part of the lives of farmers in north-east Ghana. The importance and value of diversity were revealed through the different use-values of sorghum, and the efforts made by farmers to manage and maintain their varieties in spite of constraining conditions such as inappropriate improved varieties from research, poor soils, erratic rainfall, storage pests and problems with seed quality. Farmers' efforts notwithstanding, the diagnosis showed the need to develop a research strategy to enhance farmers' knowledge and skills, in order strengthen practices of diversity management and to improve seed storage.

Chapter 3 tackles the first objective using the results of a randomized survey across the Bawku East district where the diagnostic study was conducted. Chapter 3 brings to the fore the fact that throughout the Bawku-East district, farmers were maintaining a wide range of sorghum varieties – wider, in fact than at first apparent. The chapter is important in positioning the research sites on a more general spectrum of local interest in sorghum. An important finding was the fact that, among the list of cereal crops, sorghum held a prestigious place second only to millet. In spite of farmers' concerns over unfavourable rainfall conditions, late-maturing varieties of sorghum were still being cultivated. The high number of selection criteria considered important by farmers explained why farmers cultivated several varieties of sorghum. The general argument from the results of this survey was that sorghum production seemed to be largely supported and influenced by a matrix of local beer brewing, labour provision and exchange, and traditional religious festivals. Through these influencing factors the demand for and maintenance of sorghum varieties continues to be sustained. This insight into the cultural importance of sorghum, as confirmed by data on variety use and management, leaned heavily on the application of both quantitative and qualitative social science methods. However, further methods from the bioscience disciplines were needed to establish the extent of diversity of varieties managed by farmers.

Chapter 4 addresses the second objective. In this chapter classical agro-morphological characterization and molecular techniques were employed to assess the genetic diversity of sorghum germplasm held by farmers in the district. Both techniques showed that there was considerable genetic diversity among the varieties used by farmers that could be useful for formal crop improvement programmes in Ghana. The high diversity found in panicle and grain characteristics, such as panicle compactness, grain colour, endosperm texture and endosperm colour, pointed to a readily available resource waiting to be tapped by the brewery whose main interest was in finding sorghum with specific grain characteristics and malting qualities for its products. The intra-varietal variation found within panicles of sorghum varieties confirmed observations about varietal mixtures within farmers' field. It also lent further support to the need to assist farmers to enhance their skills for variety maintenance and variation management, in order not to lose this important diversity.

The third objective was realized in Chapters 5 and 6. Chapter 5 explores the idea of convergence between stakeholders by showing how farmers and researchers could engage jointly in a scientific experimentation process to investigate inter-varietal, intra-varietal and random variation in sorghum. The use of an experimental framework (rather than a purely discursive one) to foster interaction between the knowledge systems of farmers and scientists facilitated better understanding and exchange of ideas as researchers also sought to interrogate farmers' concept of a variety at the same time. The joint learning and interaction provided evidence that a systematic exploration of scientific and local ideas aimed at points of overlap might help farmers better to link their management practices to variation revealed through experimentation. Furthermore, this overlap in knowledge systems becomes more apparent when, in application of the CoS theory of practice, farmers take part in scientific experimentation. Using the same science-based approach based on experimentation in Chapter 6, farmers and researchers engaged in research to evaluate farmers' seed storage practices to test the physiological quality of farmer-stored seed. The outcome of the experiment showed that generally, irrespective of the storage method used, the quality of farmers' seed was good. However, there was a significant difference in germination percentages between sorghum varieties, with the early-maturing varieties showing lower germination than the late-maturing varieties. The analysis showed that farmers needed to pay closer attention to the conditions under which they harvested, selected, and stored seeds of early-maturing varieties. A significant finding was that through farmers' own analysis (facilitated and stimulated by researchers) of test data, they arrived at correct inferences and displayed their ability to contribute meaningfully to research.

The fourth objective is addressed in Chapter 7. Looking at CoS within a different setting, it used a case study approach to analyse attempts to involve small-scale farmers in private-sector contract farming. The analysis of the failures in contracting showed that the making of contractual arrangements and the correct application of technology (concerning sorghum varieties in question) were two key elements crucial for making contract farming fair and viable. The role of science was considered essential for identifying and clarifying the research agenda for improving the technology, for making it work under the given environmental conditions, and for identifying and sharing the associated risk factors which farmers needed to cope with in producing sorghum. The knowledge possessed by farmers was found to be very relevant in the search for appropriate varieties for the brewery. The brewery's potential role was seen as one of investing in farmer-oriented research to improve the technology and being responsive to scientific evidence about associated production risks. This responsiveness on the part of the brewery also entails ensuring a fair distribution of these production risks within the contractual arrangements made with farmers.

The last chapter provides a synthesis of the main findings from the research and reflects on how the principles of CoS are applied in the thesis.

This thesis suggests that joint experimentation under local conditions is a useful and effective means through which unschooled small-scale farmers and scientists can actively engage in the research process. Such an approach provides the opportunity for an intensive and sustained interaction between both farmers and scientists. Going along the pathway of joint learning and experimentation has shown that farmers are capable of joining in scientific research, have an indigenous capacity for astute observation, and are capable of forming a good working notion of science as it is practiced in the formal sector. However, a conscious effort is required to embed these scientific principles in the farmers' local and cultural context in order to make the capability of farmers as co-researchers become more apparent on a sustainable basis. It is suggested, however, that the usefulness of this kind of action research, both to farmers and the wider community is hinged to maintaining scientific standards. Therefore the challenge is one of keeping a delicate balance between having a good experimental design that is recognizable and useful in the scientific world and – and at the same time – is acceptable, useful and engaging of interest and enthusiasm under farmers' conditions.

An important fact uncovered through the technographic and diagnostic studies, was that the private sector, in addition to scientific institutes and NGOs, had a potential role for a crop initially regarded as quintessentially of concern only in regard to food security of the poor. In this thesis farmers and scientists engaged in research by means of a joint learning experimental framework, but another level of interaction is envisaged whereby farmers, scientists and the private sector can also interact, using the CoS framework, and together develop sustainable relationships under market conditions for technology development. The lessons learnt from assessing recent efforts to involve farmers in sorghum contract farming in Ghana stress the fact that farmers' energy, intelligence and innovative capacity are likely to remain stifled if no ways are found to change the patron-client relationships often transferred alongside extension messages in rural development projects in many parts of rural West Africa. The case of contract farming illustrates the important lesson that making contract farming work is often contingent upon mobilizing both technical and farmer knowledge for technological problem solving. Making technology part of the contracting process helps reinforce among all contracting parties the need to work jointly towards effective solutions to production problems in an uncertain world where effective new knowledge is at a premium. This requires the recognition by contracting companies of the fact that where technology is an important issue, offering ways of negotiating about the various contributions of relevant parties in the contract to the creation of valid new knowledge would lead to better application of technology.

To conclude, the Convergence of Sciences, as an alternative approach to the linear model of planning, designing and implementing research, appears to hold much promise for isolated small farmers, such as those found in the north-eastern part of Ghana. Even though sorghum has not been top on researchers' agenda in the past it remains an important crop for farmers who stand to gain a lot more if researchers commit and apply themselves to partnership with farmers as co-researchers. This thesis has thrown some light on how such partnerships for new and effective knowledge might evolve.

Résumé

Durant ces dernières décennies, le fait que les petits paysans en Afrique au Sud du Sahara bénéficient très peu de la recherche agricole a été de plus en plus une préoccupation croissante. Un domaine clé de l'inefficience de cette recherche est l'amélioration variétale des cultures. Deux principales raisons pour lesquelles l'amélioration variétale au niveau de la recherche formelle a abouti très peu à satisfaire les besoins des paysans en Afrique au Sud du Sahara sont (i) la complexité des systèmes agro-écologiques et (ii) l'échec de créer de variétés répondant aux besoins des paysans.

De manière croissante, il a été soutenu que l'impact limité de la recherche, en particulier en Afrique où les problèmes sont divers, est lié au manque d'implication des paysans et que leur participation croissante pourrait aider la recherche à mieux s'orienter pour que les résultats des recherches soient rapidement adoptés. En réponse à ces préoccupations, des efforts ont été récemment développés à travers des approches participatives paysannes pour impliquer les paysans dans les agendas de recherche et pour mettre en place des priorités dans les besoins de développement agricoles. Cependant, réaliser un partenariat efficient entre chercheurs et paysans n'est pas aisé. Les conditions prévalentes rendent difficiles l'appropriation par les paysans des technologies agricoles de la recherche. Quand bien même les paysans africains sont souvent des innovateurs, le développement des technologies s'opère dans un contexte institutionnel et dans un cadre politique sur lesquels le paysan a peu de contrôle. D'autres acteurs de la société influencent aussi l'adoption le processus d'innovation agricole. Ce fait offre aux paysans peu d'opportunités à travers lesquelles la recherche agricole peut aider les paysans. Ainsi, le défi pour les chercheurs est de comprendre les contextes dans lesquels les paysans se sentent à l'aise pour identifier et cibler les opportunités, et de faire des choix stratégiques sur le type de recherche où il faut s'investir. Ces choix demandent que pour organiser la recherche, il faut choisir une voie différente par laquelle l'innovation agricole est reconnue comme un processus de plusieurs acteurs (y compris les paysans) où une attention particulière est portée au développement des relations d'interactions entre ces acteurs. Il n'y a pas cependant eu jusque-là une recette magique pour réaliser un tel défi.

Convergence des Sciences (CoS) suggère une approche de conduire cette forme alternative de recherche dans laquelle l'innovation agricole est reconnue et organisée comme un processus multi-acteur. Les principes de trans-disciplinarité et d'inter-disciplinarité sous-tendent l'approche CoS. La trans-disciplinarité et l'inter-disciplinarité sont deux éléments essentiels dans lesquels (1) les sciences sociales et les sciences biologiques fonctionnent ensemble de manière à contribuer à la résolution du problème dans un contexte donné, et à créer une nouvelle connaissance ou des modes de pensée; et (2) l'intégration est recherchée entre différent acteurs, y compris les chercheurs des universités, les paysans et autres groupes d'utilisateurs, tous recherchant un objectif commun de recherche. Les études technographiques et les études diagnostiques sont deux principaux outils développés par CoS pour faire des choix stratégiques consentis par rapport au type de recherche dans lequel il fallait s'investir. Une étude technographique, comme la toute première dans l'identification des problèmes, explore le paysage d'innovation pour un secteur identifié en portant un regard plus ciblé sur l'histoire des technologies, les institutions et les acteurs dans un contexte donné. Une étude diagnostique est la seconde étape d'identification du problème pour définir le problème de recherche et d'assurer que la recherche est ancrée sur les besoins et les opportunités des paysans.

Cette thèse explore les voies de conduire une recherche agricole en utilisant l'approche CoS dans un contexte de gestion et du maintien de la diversité variétale du sorgho, de sa diversité génétique, de la gestion des semences et de sa production chez les petits producteurs orientés de manière croissante vers une demande du marché. Le choix du sorgho est basé sur les études technographiques conduites au Ghana entre Janvier et Mars 2002. Il résulte de cette étude technographique (non couverte par cette thèse) que le sorgho était quelque peu une culture négligée largement produite par les petits paysans. Jusqu'à récemment, une faible priorité a été accordée à cette culture, avec une faible attention de la part des institutions nationales de recherche. L'importance du sorgho pour les paysans et l'intérêt en herbe du secteur privé (pour la brasserie) ont souligné le besoin de porter une attention plus particulière à cette culture.

Les préoccupations de l'impact limité de la recherche pour les petits producteurs en Afrique, et la nécessité de trouver des voies alternatives par lesquelles la science peut contribuer davantage au bien-être des paysans suggère que le savoir et les capacités de recherche des paysans devraient être inclus dans les efforts futurs de recherche. Cette thèse est une tentative d'exploration de ce qui est possible à cet égard, avec un accent particulier sur le sorgho. L'étude cherche à placer la science et l'initiative des paysans dans le contexte de la gestion des ressources génétiques du sorgho et à répondre à deux questions principales

- Comment et dans quels domaines les paysans et chercheurs peuvent efficacement s'engager dans une recherche agricole pour une gestion et une utilisation durables des ressources génétiques sorgho au Ghana?
- Quelles leçons l'approche CoS fournit aux efforts futurs dans la conception et la conduite d'une recherche pertinente pour les petits paysans?

Pour répondre à ces questions, il a été nécessaire de déterminer d'abord le type de recherche qui serait utile aux paysans en étudiant les contraintes, les besoins, les stratégies, le savoir et les compétences des paysans dans l'utilisation et la gestion des ressources génétiques sorgho. A partir de l'étude diagnostique, quatre objectifs spécifiques ont été adressés par cette recherche:

- Déterminer comment les paysans gèrent et utilisent leurs variétés de sorgho et les facteurs influençant cette gestion.
- Déterminer la diversité génétique des variétés du sorgho, comme gérée par les paysans.
- Déterminer le savoir et savoir-faire des paysans par rapport au stockage des semences et à la gestion de la diversité, avec un regard d'un possible renforcement de capacité pour le maintien de la diversité et de la production d'une semence de qualité.
- Explorer comment de nouvelles relations peuvent être créées et soutenues entre chercheurs, paysans, et le secteur privé en réponse aux conditions de demande croissante de la production du sorgho pour le marché.

Cette thèse est divisée en huit chapitres:

Le chapitre 1 est le chapitre introductif de la thèse. Il présente les problèmes qui ont été adressés et offre un aperçu sur les autres chapitres.

En utilisant l'approche diagnostique, le chapitre 2 présente le contexte de l'étude technographique. Au sein des systèmes de culture, le sorgho apparaît comme une culture qui perd de plus en plus son importance par rapport au maïs et constitue une part intégrale de la vie des paysans du Nord-Est du Ghana. L'importance et la valeur de la diversité du sorgho sont analysées à travers les valeurs d'utilité du sorgho et les efforts menés par les paysans pour gérer et maintenir les variétés malgré les conditions contraignantes telles que la non appropriation des variétés améliorées de la recherche, la pauvreté des sols, les pluies erratiques, les insectes de stockage des grains et les problèmes de la qualité des semences. Malgré les efforts des paysans, le diagnostic a montré le besoin de développer une stratégie de recherche pour renforcer le savoir et savoir-faire des paysans, pour pouvoir améliorer les pratiques de gestion de la diversité et de la qualité de stockage.

Le chapitre 3 aborde le premier objective par une enquête réalisée à l'est du district de Bawku où l'étude diagnostique a été conduite. Ce chapitre met en avant le fait que dans cette partie Est du district de Bawku, les paysans continuaient à maintenir une diversité de variétés de sorgho, une diversité plus large qu'il n'apparaissait au premier regard. Le chapitre est aussi important dans la sélection des sites de recherche d'intérêt plus général au sorgho. L'un des résultats les plus importants était que dans la liste des cultures, le sorgho occupait une position privilégiée après le millet. Malgré les préoccupations des paysans par rapport aux conditions pluviométriques non favorables, les variétés de long cycle étaient toujours cultivées. Le grand nombre de critères considérés importants par les paysans expliquaient pourquoi ils cultivaient plusieurs variétés de sorgho. L'argument général de cette étude était que le système de production du sorgho semblait être largement supporté et influencé par une matrice de brasseries locales, de travail et d'échange, et de valeurs religieuses traditionnelles. A travers ces facteurs influents, la demande pour et le maintien des variétés continuaient à être soutenus. Cette vue sur l'importance de la valeur culturelle du sorgho, comme confirmée par les données sur l'utilisation et la gestion variétale, enseignent suffisamment sur l'application des méthodes qualitatives et quantitatives en sciences sociales. Cependant, d'autres méthodes en sciences biologiques ont été ultérieurement nécessaires pour établir l'ampleur de la diversité des variétés gérées par les paysans.

Le chapitre 4 s'adresse au deuxième objectif. Dans ce chapitre les techniques classiques de caractérisation agro-morphologique et moléculaire ont été utilisées pour évaluer la diversité génétique du sorgho dans ce district. Ces techniques ont révélé l'existence d'une importance diversité génétique au sein de ces variétés qui peuvent être utiles pour les programmes d'amélioration variétale au Ghana. La large diversité trouvée sur les caractéristiques des panicules et des grains, telles que la compacité des panicules, la couleur des grains, la texture et la couleur de l'endosperme, pointait du doigt la potentialité de la ressource qui reste à découvrir par la brasserie dont l'intérêt particulier était de trouver des variétés de sorgho de caractéristiques de grains spécifiques et qualités distinguées de malt. La variation intra-variétale trouvée au sein des panicules du sorgho a confirmé les observations du mélange de variétés au sein des champs paysans. Cela conduisait au support de l'idée d'assister les paysans à renforcer leur savoir-faire de maintien et de gestion de la diversité, pour ne pas perdre cette diversité.

Le troisième objectif est atteint à travers les chapitres 5 et 6. Le chapitre 5 explore l'idée que la convergence entre les acteurs en montrant comment les paysans et les chercheurs pourraient s'engager conjointement dans un processus scientifique d'expérimentation pour analyser la variation inter et intra-variétale chez le sorgho. L'utilisation du cadre expérimental est de stimuler une interaction entre les systèmes de savoir paysan et scientifique pour faciliter une meilleure compréhension et l'échange d'idées comme les chercheurs cherchent à interroger le concept paysan d'une variété au même moment. L'apprentissage conjoint et l'interaction ont fourni l'évidence qu'une exploration systématique des idées scientifiques et locales visant à se coïncider pourrait davantage aider à mieux lier les pratiques de gestion aux variations révélées à travers l'expérimentation. En outre, ce recouvrement entre les systèmes de savoir est devenu plus apparent quand, dans la mise en application de la théorie CoS, les paysans doivent prendre part importante à l'expérimentation scientifique. En utilisant la même approche scientifique basée sur l'expérimentation dans le chapitre 6, les paysans et chercheurs se sont engagés dans la recherche pour évaluer les pratiques paysannes de stockage des semences et de tester la qualité physiologique de semence stockée par les paysans. Le résultat de cette expérimentation a montré que généralement, sans tenir compte de la méthode utilisée, la qualité des semences stockées par les paysans était bonne. Cependant, il y a une différence significative dans la germination entre les variétés de sorgho, les variétés précoces montrant une germination plus faible que les variétés de cycle long. L'étude a révélé que les paysans ont besoin de porter plus d'attention aux conditions sous lesquelles elles ont été récoltées, sélectionnées, et les conditions de stockage des variétés précoces. L'un des résultats importants était les analyses personnelles des paysans à travers les tests des données (facilitées et stimulées par les chercheurs). Les paysans parvenaient aux correctes conclusions et montraient leur habileté de contribuer significativement à la recherche.

Le chapitre 7 s'adresse au quatrième objectif. Ce chapitre est une étude de cas de l'approche CoS dans un cadre différent qui analyse les possibilités d'implication des petits producteurs dans le secteur privé à travers le contrat d'exploitation. L'analyse des échecs du contrat d'exploitation a montré que les arrangements contractuels et l'application correcte de la technologie ayant rapport aux variétés de sorgho sont deux éléments clés, cruciaux dans la mise en œuvre d'un contrat d'exploitation juste et viable. Le rôle de la science est considéré comme essentiel dans l'identification et la clarification de l'agenda de recherche pour améliorer la technologie, pour la rendre fonctionnelle par rapport aux conditions environnementales, et pour identifier et partager les facteurs de risques que les paysans doivent prendre en compte dans la production du sorgho. Les connaissances détenues par les paysans sont essentielles dans la recherche des variétés appropriées pour la brasserie. Le rôle essentiel de la brasserie est perçu comme celui d'investissement dans la recherche orientée par les paysans pour améliorer la technologie et pour répondre à l'évidence scientifique des risques associés de production. La réponse de la brasserie suppose l'assurance d'une distribution équitable des risques de production au sein des arrangements contractuels faits avec les paysans.

Le dernier chapitre offre une synthèse des principaux résultats de la recherche et porte une réflexion sur comment les principes CoS ont été appliqués dans cette thèse.

Cette thèse suggère que l'expérimentation conjointe dans les conditions locales est un moyen utile et efficace à travers lequel les petits paysans analphabètes et les

scientifiques peuvent activement s'engager dans un processus de recherche. De telle approche offre l'opportunité d'une interaction intensive et soutenue entre les paysans et les scientifiques. En suivant la voie d'un apprentissage et d'une expérimentation conjoints, il en est ressorti que les paysans sont coopératifs dans la recherche scientifique, font des observations subtiles et pertinentes, et sont dotés d'une bonne notion du travail scientifique comme il est pratiqué dans le secteur formel. Cependant, un effort conscient est demandé pour ancrer ces principes scientifiques dans le contexte local et culturel des paysans et pour durablement faire de ces paysans des co-chercheurs reconnus par le public scientifique. Il est suggéré toutefois que l'utilité de ce type de recherche action est bâtie dans le maintien des normes scientifiques à la fois pour les paysans et la grande communauté. Ainsi le défi reste de maintenir un équilibre entre le protocole expérimental reconnaissable par le grand public scientifique et au même moment acceptable, utile, et engageant l'enthousiasme dans les conditions des paysans.

Un important aspect non couvert par les études technographiques et diagnostiques est que le secteur privé, les institutions de recherche scientifique et les ONG ont un rôle potentiel à jouer pour une culture initialement vue comme une préoccupation de la sécurité alimentaire des pauvres. Dans cette thèse, les paysans et les scientifiques se sont engagés dans la recherche de moyens d'un cadre d'apprentissage et d'expérimentation conjoint. Mais un autre niveau d'interaction pertinent apparaît dans ce cadre CoS entre paysans, scientifiques et le secteur privé pour développer des relations durables du développement technologique dans les conditions du marché. Les leçons de l'évaluation des efforts d'impliquer les paysans dans le contrat d'exploitation du sorgho au Ghana met l'accent sur le fait que les énergies, l'intelligence et la capacité d'innovation des paysans peuvent rester étouffées s'il n'existe pas d'alternative pour changer la relation patron - client qui a longtemps gouverné les messages au sein des projets de développement rural en plusieurs endroits de Afrique de l'Ouest. Le cas du contrat d'exploitation illustre bien une importante leçon qui fait que le bon fonctionnement du contrat d'exploitation dépend de la mobilisation du savoir technique et du savoir paysan pour résoudre les problèmes technologiques. En faisant de la technologie comme une part intégrante du contrat d'exploitation aide à renforcer le besoin de travail conjoint des parties contractantes pour trouver des solutions efficaces aux problèmes de production dans un contexte d'incertitude où une nouvelle connaissance efficace est primée. Ceci demande une reconnaissance de la part des entreprises contractantes que la technologie est une importante question, offrant des voies de négociations sur les différentes contributions des parties contractantes pour créer un nouveau savoir qui pourrait conduire à une meilleure application de la technologie.

Pour conclure, l'approche Convergence des Sciences est une approche alternative au modèle linéaire de conception, de planification et d'exécution des protocoles de recherche. Cette approche s'annonce prometteuse pour les petits paysans isolés comme ceux du nord-est du Ghana. Quand bien même dans le passé le sorgho n'est pas été priorisé au niveau de l'agenda de la recherche, il demeure une importante culture pour les paysans qui espèrent y tirer beaucoup de profits si les chercheurs s'engagent et s'appliquent dans un partenariat avec les paysans comme co-chercheurs. Cette thèse a projeté une certaine lumière sur comment un tel partenariat pour un savoir nouveau et efficace pourrait se développer.

Samenvatting

Gedurende de laatste decennia is de zorg toegenomen over het feit dat kleinschalige Afrikaanse boeren ten zuiden van de Sahara onvoldoende hebben geprofiteerd van landbouwkundig onderzoek. Er bestaan vooral zorgen over het geringe effect dat het onderzoek heeft gehad op de verbetering van gewassen. Algemeen wordt aangenomen dat de formele instituties vooral zo weinig voor het verbeteren van de gewassen in dit deel van Afrika hebben kunnen betekenen omdat de landbouwsystemen hier erg complex zijn en omdat er geen nieuwe rassen beschikbaar kwamen die voldeden aan de eisen van de boeren.

De gedachte heeft terrein gewonnen dat het gebrek aan invloed van het onderzoek, (vooral in Afrika, waar de landbouwkundige problemen divers zijn) te maken heeft met het feit dat boeren niet rechtstreeks betrokken zijn bij het onderzoek. Als boeren actiever in het onderzoek zouden participeren, dan kan het onderzoek beter op hun behoeften afgestemd worden en kunnen onderzoeksresultaten ook sneller toegepast worden. In reactie op deze redenering zijn er in het recente verleden pogingen gedaan om participatieve benaderingen te ontwikkelen waarin boeren actief werden betrokken bij het opstellen van de onderzoeksagenda, in het plannen van het onderzoek en in de prioriteitsstelling. Het valt echter niet mee om onderzoekers en boeren effectief in het onderzoek aan elkaar te koppelen. De heersende omstandigheden maken het voor boeren moeilijk om zich de technologieën die door landbouwkundig onderzoek worden ontwikkeld, eigen te maken. Ondanks het feit dat Afrikaanse boeren als zeer innovatief beschouwd kunnen worden, moeten we vaststellen dat de ontwikkeling van technologie plaatsvindt in een wijde, institutionele context en in een beleidskader waarover boeren weinig controle hebben. Andere maatschappelijke belanghebbenden hebben ook invloed op het landbouwkundige innovatieproces. Daardoor hebben boeren maar een beperkte speelruimte waarin het landbouwkundig onderzoek dienstig kan zijn. Het is dan de uitdaging voor de onderzoekers om de context waarin de boeren zich bevinden te doorgronden, om de mogelijkheden te ontdekken en om gefundeerde strategische keuzes te maken in welk type onderzoek te investeren. Dit is alleen mogelijk als het onderzoek op een andere manier wordt georganiseerd, en wel in dier voege dat landbouwkundige innovatie wordt gezien als een proces met vele belanghebbenden, waaronder onderzoeksinstellingen en andere maatschappelijke belangengroepen (waaronder boeren), waarbij aandacht wordt besteed aan het ontwikkelen van wisselwerkingen tussen die vele belanghebbenden. Er bestaat echter geen algemeen geaccepteerde manier om dit op te pakken.

Het programma "Convergence of Sciences" (CoS) denkt een benadering te hebben

gevonden om deze alternatieve methode van onderzoek vorm te geven. De benadering wordt gekenmerkt door het feit dat innovaties in de landbouw worden beschouwd en behandeld als een proces waarbij vele belanghebbenden betrokken zijn. De onderliggende principes van de CoS-benadering zijn transdisciplinariteit en interdisciplinariteit. Trans- en interdisciplinariteit zijn twee belangrijke elementen waarin

(1) De maatschappijwetenschappen en de natuurwetenschappen samenwerken om een probleem binnen een gegeven context op te lossen, en zo nieuwe kennis of nieuwe denkwijzen te scheppen;
(2) Nadrukkelijk naar integratie wordt gestreefd tussen verschillende belanghebbenden, onder wie universitaire onderzoekers, boeren en deelnemers uit andere gebruikersgroepen. Deze verschillende belanghebbenden streven allen naar een gemeenschappelijk doel.

Ten einde gefundeerde strategische keuzes te kunnen maken betreffende het onderzoek waarin geïnvesteerd moet worden, heeft CoS twee belangrijke onderzoeksinstrumenten ontwikkeld: technografische studies en diagnostische studies. Een technografische studie is een eerste stap in de probleemidentificatie. Een dergelijke studie verkent het innovatielandschap van een bepaalde sector door te kijken naar de geschiedenis van de technologieontwikkeling, instituties en belanghebbenden binnen een gegeven context. Een diagnostische studie is een tweede stap in de probleemidentificatie; een dergelijke studie definieert het te onderzoeken probleem, maar zorgt er tevens voor dat het onderzoek verankerd is in de behoeften, mogelijkheden en kansen van boeren.

Dit proefschrift is een verkenning van de mogelijkheden om met de CoS-benadering in de hand, landbouwkundig onderzoek te doen naar het beheer van diversiteit, het in standhouden van rassen, de genetische diversiteit, zaaizaadbeheer en landbouwkundige productie. Er is er voor gekozen dat te doen voor de sorghumteelt bij kleinschalige boeren in het noordoosten van Ghana. De omstandigheden zijn daar nog sterk gericht op zelfvoorziening, maar de invloed van de markt wordt steeds groter. De keuze voor sorghum is gebaseerd op de technografische studie, uitgevoerd in Ghana, van januari – maart 2002, die overigens niet in het proefschrift wordt beschreven. Deze studie gaf aan dat sorghum een enigszins verwaarloosd gewas voor de lokale bevolking is, dat op grote schaal door kleinschalige boeren wordt geteeld. Tot voor kort werd er weinig prioriteit aan dit gewas gegeven en ook de nationale onderzoeksinstituten schonken maar weinig aandacht aan dit gewas. Maar omdat het gewas zo belangrijk is voor de boeren en omdat ook de private sector interesse in sorghum begon te krijgen (om als grondstof voor het brouwen van bier te gebruiken) bestond er grote behoefte om meer aandacht aan dit gewas te gaan besteden.

Er bestaan zorgen over de beperkte invloed van onderzoek op het handelen van kleinschalige boeren in Afrika. Daarom is er een roep om een alternatief stappenplan ten einde te komen tot een grotere bijdrage aan de levensomstandigheden van boeren. Dit geeft aanleiding om serieus te proberen de kennis en onderzoeksvaardigheden van de boeren zelf te benutten. Dit proefschrift tracht te verkennen wat op dit terrein mogelijk is en doet dat met speciale aandacht voor sorghum. Daarbij gaat het er vooral om wetenschap en boereninitiatief te plaatsen binnen de context van het beheren van genetische bronnen van sorghum. Het proefschrift beoogt daartoe de volgende twee hoofdvragen te beantwoorden:

- Hoe en op welke terreinen kunnen boeren en wetenschappers samen op effectieve wijze betrokken zijn bij het ontwikkelen van een duurzaam gebruik en beheer van genetische bronnen van sorghum in Ghana?
- Welke lessen kunnen uit de CoS benadering worden getrokken ten einde in de toekomst onderzoek te ontwerpen en uit te voeren dat relevant is voor de omstandigheden van de kleine boer?

Om deze vragen te beantwoorden was het allereerst belangrijk te bepalen welk type onderzoek bruikbaar bevonden werd voor de boeren, door vast te stellen wat de beperkingen, behoeften, strategieën, kennisniveau en vaardigheden van de boeren waren met betrekking tot het beheren van genetische bronnen van sorghum. Op basis van een diagnostische studie werden vier specifieke doelstellingen voor dit onderzoek geformuleerd:

- Vaststellen hoe boeren hun sorghumrassen benutten en beheren, en vaststellen welke factoren daarop van invloed zijn.
- Vaststellen hoe groot de door boeren beheerde genetische diversiteit van sorghumrassen is.
- Vaststellen wat boeren weten met betrekking tot zaadopslag en beheer van diversiteit en welke technieken ze daarbij gebruiken. Kennis hieromtrent kan wellicht de lokale mogelijkheden van instandhouding van rassen en productie van kwalitatief goed zaad versterken.
- Verkennen hoe nieuwe relaties tussen onderzoekers, boeren en de private sector in het leven kunnen worden geroepen en duurzaam kunnen worden gemaakt onder omstandigheden waarbij de markt voor sorghumproductie een belangrijke rol speelt.

Het proefschrift is ingedeeld in 8 hoofdstukken.

Hoofdstuk 1 geeft een algemene inleiding op het onderzoek, beschrijft de problemen die worden aangepakt en biedt een overzicht van de inhoud van de volgende hoofdstukken.

Op basis van een diagnostische studie en redenerend vanuit de resultaten van een technografische studie geeft Hoofdstuk 2 een contextueel overzicht. Binnen het gebruikelijke teeltsysteem bleek sorghum een belangrijk gewas, ook al verliest het terrein aan maïs. Sorghum vormt een integraal onderdeel van het bestaan van de boeren van noordoost Ghana. Sorghum is belangrijk en waardevol omdat het een veelheid van toepassingen kent. Boeren besteden dan ook veel aandacht aan het beheren en instandhouden van hun rassen, ook al zijn de omstandigheden daarvoor niet eenvoudig. Problemen zijn onder andere ongeschikte rassen, voortgebracht door het institutionele onderzoek, slechte bodems, onbetrouwbare regenval, bewaarziektes en problemen met kwaliteit van zaaizaad. Ondanks alle inspanningen van de boeren, bestaat er volgens de diagnostische studie nog steeds een grote behoefte aan het ontwikkelen van een onderzoeksstrategie die het mogelijk maakt de kennis en vaardigheden van boeren te bevorderen en hen op die manier in staat te stellen betere technieken te gebruiken voor beheer van diversiteit en bewaring van zaaizaad.

In Hoofdstuk 3 wordt beschreven wat er ten aanzien van de eerste specifieke doelstelling is gedaan. Dit gebeurt op grond van de resultaten van onderzoek in hetzelfde gebied waarin ook de diagnostische studie was uitgevoerd. Hoofdstuk 3 toont aan dat de boeren in het gehele Bawku-East district een breed spectrum aan rassen instandhielden, veel breder dan eerst was aangetoond. Het hoofdstuk is belangrijk omdat het de onderzoekslocaties plaatst in het kader van een meer algemeen spectrum van lokale interesse in sorghum. Een belangrijke ontdekking was het feit dat sorghum binnen de granen een belangrijke plaats innam. Alleen gierst was nog belangrijker. Hoewel boeren zich zorgen maakten over de ongunstige regenval, teelden zij nog steeds late sorghumrassen. Boeren verbouwden verschillende rassen van sorghum omdat zij veel verschillende selectiecriteria van belang achtten. Belangrijke factoren die de teelt van sorghum beïnvloedden, waren de behoefte om bier te brouwen van sorghum, de beschikbaarheid en uitwisseling van arbeid en de traditionele religieuze feesten. Vanwege deze uiteenlopende factoren bleef de vraag naar en de instandhouding van sorghumrassen ook duurzaam. Dit inzicht in het culturele belang van sorghum werd ondersteund door de gegevens over het gebruik en het beheer van de verschillende rassen. Deze gegevens konden slechts worden verkregen door het toepassen van kwantitatieve en kwalitatieve methoden uit de sociale wetenschappen. Om echter de omvang van de diversiteit van de door de boeren beheerde rassen goed in kaart te brengen waren methodes uit de biologische wetenschappen onontbeerlijk.

In Hoofdstuk 4 werd de tweede specifieke doelstelling uitgewerkt. In dit hoofdstuk werden naast klassieke agro-morfologische karakterisering moleculaire technieken gebruikt om de genetische variatie in het sorghum kiemplasma zoals dat door de boeren in het district in stand werd gehouden, vast te stellen. Met beide technieken kon worden aangetoond dat er een aanzienlijke genetische diversiteit bestond onder de rassen die door de boeren werden geteeld. Deze diversiteit zou nuttig kunnen zijn voor de formele veredelingsprogramma's in Ghana. Er werd vooral een grote diversiteit gevonden in de eigenschappen van de pluim en van de korrel, waaronder de compactheid van de pluim, de kleur van de korrels, en de textuur en kleur van het endosperm. Deze diversiteit kan een belangrijke en toegankelijke hulpbron betekenen voor de bierbrouwerij, die vooral geïnteresseerd was in het vinden van een sorghum die over de juiste korreleigenschappen beschikt voor het moutproces. Het onderzoek toonde ook belangrijke variatie binnen de rassen en zelfs binnen pluimen aan. Deze variatie wijst op het gebruik van rassenmengsels. Maar deze variatie toont tevens aan dat boeren ondersteuning behoeven bij het ontwikkelen van vaardigheden op het terrein van het instandhouden en beheren van hun rassen, ten einde deze belangrijke bron van diversiteit niet te verliezen.

In de Hoofdstukken 5 en 6 kwam de derde doelstelling aan bod. In Hoofdstuk 5 wordt het idee uitgewerkt om verschillende belanghebbenden bij elkaar te brengen. Het hoofdstuk laat zien hoe boeren en onderzoekers samen betrokken kunnen raken in een proces van wetenschappelijk proefneming ten einde de variatie in sorghum veroorzaakt door tussen-ras, binnen-ras en toevallige verschillen te onderzoeken. Door te werken in een experimenteel kader (in plaats van door louter op basis van argumenten te discussiëren) werd een communicatie over en weer geschapen tussen de kennissystemen van boeren en wetenschappers. Dit kader bleek het wederzijdse begrip en de uitwisseling van ideeën te faciliteren, onder andere doordat de wetenschappers de boeren gingen bevragen op hun idee wat een ras nu precies was. Hierdoor ontstond een gezamenlijk en interactief leerproces dat aantoonde dat een systematische verkenning van wetenschappelijke en aangeboren ideeën, gericht op het ontdekken van gezamenlijkheid, boeren kan bijstaan in het koppelen van hun beheersmaatregelen aan de met de experimenten aangetoonde variatie. Bovendien wordt de overlap in de kennissystemen veel beter zichtbaar wanneer boeren (conform de toepassing van de CoS theorie over de praktijk) deelnemen aan het proces van wetenschappelijke proefneming. In Hoofdstuk 6 werd dezelfde op wetenschappelijke proefneming gebaseerde benadering toegepast op een heel ander thema. Boeren en onderzoekers onderzochten samen het effect van verschillende boerenbewaarmethoden van zaaizaad op de fysiologische kwaliteit er van. Het onderzoek toonde aan dat, ongeacht de bewaarmethode, de kwaliteit van het zaaizaad over het algemeen goed was. Er werden echter significante verschillen gevonden in kiemingspercentage tussen de verschillende sorghumrassen: vroege rassen hadden een lager kiempercentage dan late rassen. De analyse toonde aan dat boeren meer aandacht moesten besteden aan de omstandigheden waaronder ze de zaden van vroege rassen oogstten, selecteerden en bewaarden. Een belangrijke uitkomst van het onderzoek was dat boeren op grond van hun eigen analyse van de testgegevens (daartoe gefaciliteerd en gestimuleerd door de onderzoeker) in staat waren om te komen tot correcte gevolgtrekkingen. Boeren toonden daarbij aan in staat te zijn op een betekenisvolle wijze aan het onderzoek te kunnen bijdragen.

De vierde specifieke doelstelling komt aan bod in Hoofdstuk 7. In dit hoofdstuk wordt, vanuit een ander gezichtspunt op CoS, een case study benadering toegepast om pogingen te beschrijven kleinschalige boeren te betrekken bij de contractteelt voor een bedrijf uit de private sector. Er werd een analyse gepleegd wat de contractteelt deed mislukken. Het maken van de contractafspraken en de juiste toepassing van technologie (in dit geval de juiste keuze van het sorghumras) bleken twee belangrijke elementen te zijn in het realiseren van een contractteelt die eerlijk en uitvoerbaar was. De wetenschap moet daarbij een belangrijke rol spelen ten einde de onderzoeksagenda vast te stellen en uit te leggen die moet leiden tot een verbeterde technologie, en die er toe moet leiden dat de contractteelt gaat werken onder de gegeven milieu-omstandigheden. De wetenschap moet ook de aan de contractteelt verbonden risico's identificeren en ervoor zorgen dat die risico's werden gedeeld als boeren sorghum gaan telen voor de brouwerij. De boeren bleken te beschikken over kennis die relevant was voor het kiezen van de geschikte rassen voor de brouwerij. De mogelijke rol van de brouwerij zou er een kunnen zijn gericht op het investeren in op de boer gericht onderzoek, om de technologie te verbeteren, en om open te staan voor wetenschappelijk bewijs betreffende de risico's die met de contractteelt verbonden zijn. Het op een juiste wijze reageren vanuit de brouwerij brengt ook met zich mee dat de brouwerij een eerlijke verdeling van deze productierisico's zou kunnen garanderen, binnen de contractafspraken die met de boeren zijn gemaakt.

Het laatste hoofdstuk geeft een synthese van de belangrijkste uitkomsten van het onderzoek en een reflectie op de wijze waarop de principes van CoS zijn toegepast in dit proefschrift.

Dit proefschrift suggereert dat gezamenlijke proefnemingen onder lokale condities een bruikbaar en effectief instrument zijn, waarmee ongeschoolde kleinschalige boeren en wetenschappers samen actief bij het onderzoekproces betrokken kunnen geraken. Een dergelijke benadering biedt de gelegenheid voor een intensieve en duurzame communicatie over en weer tussen boeren en wetenschappers. Door samen het pad op te gaan van gezamenlijk leren en experimenteren is aangetoond dat boeren in staat zijn mee te doen in wetenschappelijk onderzoek, dat zij een aangeboren vermogen hebben om scherp waar te nemen en in staat zijn zich een goed beeld te vormen van wat wetenschap zoals die wordt beoefend in de formele sector, inhoudt. Maar er is een bewuste inspanning nodig om de wetenschappelijke principes uit de formele sector in te bedden in de lokale en culturele context van de boeren, ten einde het vermogen van boeren mede onderzoek te doen op een duurzame basis zichtbaar te maken. De bruikbaarheid van dit soort actieonderzoek, zowel voor de boeren als voor een bredere gemeenschap, zou echter wel eens kunnen afhangen van het handhaven van wetenschappelijke standaarden. Het is daarom een uitdaging, om de delicate balans te vinden tussen een goed proefontwerp dat herkenbaar en bruikbaar is in de wetenschappelijke wereld en tegelijkertijd acceptabel en bruikbaar is voor de boeren, maar tevens hun interesse en enthousiasme wekt.

De technografische en diagnostische studies leverden de belangrijke uitkomst op dat de private sector, naast de wetenschappelijke instituties en de niet-gouvernementele organisaties, een potentiële rol heeft voor de ontwikkeling van een gewas dat aanvankelijk slechts werd beschouwd als een gewas dat alleen van belang was voor de voedselzekerheid van de armen. In dit poefschrift hebben boeren en onderzoekers samen onderzoek uitgevoerd, via een gezamenlijk traject van leren door te experimenteren. Maar er bestaat ook een ander niveau van interactie: boeren, onderzoekers en vertegenwoordigers van de private sector kunnen ook – gebruikmakend van het CoS denkkader – interacteren en gezamenlijk duurzame relaties ontwikkelen ten einde technologieën te ontwikkelen in een marktgestuurde omgeving. De lessen die getrokken worden uit het beschrijven van de inspanningen om boeren te betrekken bij de contractteelt van sorghum in Ghana onderstrepen het feit dat de energie, de intelligentie en het innoverende vermogen van boeren waarschijnlijk sterk worden onderdrukt of zelfs gesmoord, als er geen manier wordt gevonden om de patroon-client relaties te veranderen die zo vaak worden overgedragen via de voorlichtingsboodschappen in plattelandsontwikkelingsprojecten in vele delen van ruraal West Afrika. Het voorbeeld van de contractteelt in sorghum laat de belangrijke les zien dat ten einde contractteelt te laten werken men vaak afhankelijk is van het mobiliseren van zowel de technische kennis als de boerenkennis voor het oplossen van een technologisch probleem. Als de technologie onderdeel wordt gemaakt van het contracteren dan kan dat de behoefte bij alle partijen om samen te werken naar effectieve oplossingen versterken. Dit geldt vooral voor oplossingen voor productie-problemen in een onzekere wereld waar effectieve nieuwe kennis essentieel is. Hiervoor is bij contracterende bedrijven de erkenning nodig van het feit dat waar technologie een belangrijk thema is, het bieden van mogelijkheden om over de verschillende bijdragen aan het scheppen van de nieuwe, deugdelijke kennis door de onderscheiden relevante contractpartijen te onderhandelen, zal leiden tot een betere toepassing van de technologie.

Ten slotte kan gesteld worden dat de Convergence of Sciences, als een alternatieve benadering ten opzichte van het lineaire model van planning, ontwerp en uitvoeren van onderzoek, veelbelovend is voor geïsoleerde kleine boeren, zoals we ze aantreffen in het noordoosten van Ghana. Ondanks het feit dat sorghum vroeger niet bovenaan de agenda van de onderzoekers stond, blijft het een belangrijk gewas voor de boeren die veel verder kunnen komen indien onderzoekers zichzelf committeren en zich gaan zien als partners met de boeren als medeonderzoekers. Deze thesis heeft wat licht geworpen op de vraag hoe dergelijke partnerschappen nieuwe en effectieve kennis zouden kunnen ontwikkelen.

Appendix 1

Sorghum seed system survey- Bawku East district

Under the Convergence of Sciences Research Project a study is being carried out on sorghum production systems in the Bawku East District of the Upper East Region, Ghana. The purpose of this survey is to obtain information about sorghum farmers with respect to their farming systems, cropping pattern, seed sources, production, selection and exchange. The information gathered is for the purpose of this research and would be useful in improving the knowledge base of all who work with sorghum farmers and relevant stakeholders in the sorghum industry.

Name of interviewer: Date:

I. Personal data & Farming System

1. Farmer's Name …………………………..
2. Gender M/F
3. Age: ………………………
4. Religion: ………………………
5. Ethnicity: ………………………
6. Village/District ……………………………
7. Main occupation…………………………………..
8. Other sources of income in order of importance
   …………………………….
   …………………………….
   …………………………….
9. Size of farm (acres)
   1-compound ………………
   2-distant …………………..
10. Size of household
    ……………………………
11. Use of external labour in farming activities
    1 = No
    2 = exchange with neighbours
    3 = labour in exchange for seeds, grain, food
    4 = hire paid labour
    5 = other

12. Important information sources on agricultural activities
    1 = relatives, friends, community
    2 = agriculture extension service
    3 = radio
    4 = other (indicate)

II Cropping Pattern and Use of Varieties

13. Indicate from the table below which crops are grown, cropping sequence and the main purpose for which they are grown.

Crops	Previous Crop	Consumption	Market	Other
Late millet	……	……	……	……
Early millet	……	……	……	……
Maize	……	……	……	……
Sorghum	……	……	……	……
Cotton	……	……	……	……
Rice	……	……	……	……
Sweet potato	……	……	……	……
Soybean	……	……	……	……
Cowpea	……	……	……	……
Groundnut	……	……	……	……
Bambara groundnut	……	……	……	……
Onion	……	……	……	……
Okro	……	……	……	……
Tomato	……	……	……	……
Other	……	……	……	……

14. Rank the cereals you grow according to the proportion of land allocated to each one.

Cereal	Ranking
Millet	………………………
Sorghum	………………………
Maize	………………………
Rice	………………………
……	………………………

15. Provide in the table below the required information on the different varieties of sorghum you grow. (Household)

Sorghum variety	No. of years grown	Reasons for growing (desirable traits)	Uses of variety
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……
……	……	……	……

16. Indicate the varieties you know but do not grow and the reasons for not growing them. (Household)

Variety not grown	Reasons for not growing
……	……
……	……
……	……
……	……
……	……
……	……
……	……
……	……

17. Indicate the sorghum plant trait/characteristics most important to you.
    1 - ………………………………
    2 - ………………………………
    3 - ………………………………
    4 - ………………………………
    5 - ………………………………

18. Do you grow specific sorghum varieties on specific types of land? Yes/No
    Why?
    …………………………………………………………….

19. Do you grow mixtures of sorghum varieties on the same piece of land? Yes/No
    Why?
    …………………………………………………………….

20. Has there been a shift in your choice of sorghum varieties over the past 5-10 years? Yes/No
    Why?
    …………………………………………………………………………..

III. Seed sources and exchange

21. Please provide the following information on the sorghum varieties you grow.

Variety	Source of seed 1 = Own seed 2 = Other farmers in village 3 = Farmers in another village 4 = Market 5 = MoFA 6 = Other	Name of market(s) and village(s) from which seed is sourced	Means of obtaining seeds 1 = Cash 2 = Exchange for seed or grain 3 = Exhange for labour 4 = Share cropping 5 = Gift	Reason for using seed from other source 1 = Better seed quality 2 = Eat/sell seeds before season 3 = Other (indicate)
……	……	……	……	……
……	……	……	……	……
……	……	……	……	……
……	……	……	……	……
……	……	……	……	……
……	……	……	……	……

22. Are you interested in new varieties of sorghum?
    …………………………………………….

23. How do you obtain seeds of new sorghum varieties?
    ………………………………………………………………………………………

IV. Seed production and Storage

24. Please indicate how you produce and select sorghum seed (Household)

Variety	Production	Selection
	1 = Cultivate a portion for seed 2 = Use seed from farm 3 = other (indicate)	1 = Select panicles in field before harvest 2 = Select panicles during harvest 3 = Select panicles after harvest 4 = Select panicles during storage/just before planting
……	……	……
……	……	……
……	……	……
……	……	……

25. In selecting sorghum seed what characteristics do you select for?

   ……………………………….
   ……………………………….
   ……………………………….
   ……………………………….
   ……………………………….

26. Who selects the seed?

   1= Women   2= Men   3= Both men and women

27. Who stores sorghum seed?

   1= Women mainly   2= Men mainly   3= Men and women

28. Indicate the form in which sorghum <u>seeds</u> are stored and treated for the varieties you grow. (Household)

Variety	How stored	Storage place	Form in which seed is stored	Seed treatment before storage	Treatment during storage
	1 = With grain 2 = Separately	1 = Grass barn 2 = Mud silo 3 = Room in compound 4 = In kitchen 5 = Open air from roof 6 = On trees 7 = In sacks 8 = Clay pots	1 = Threshed 2 = On the panicle	1 = None 2 = Chemicals 3 = Wood ash 4 = other (indicate)	1 = None 2 = Chemicals 3 = Wood ash 4 = Sun drying 5 = other (indicate)
……	……	……	……	……	……
……	……	……	……	……	……
……	……	……	……	……	……
……	……	……	……	……	……

29. What form of storage containers do you use for sorghum grain?
    1 = mud silos
    2 = grass barns
    3 = other ……………….

30. Indicate the level of importance of the following in assessing or choosing what variety of sorghum to grow.

Trait	Very important	Somewhat important	Not important
Early maturing	……	……	……
Yield	……	……	……
Taste	……	……	……
Resistant to birds	……	……	……
Drought tolerance	……	……	……
Resistant to lodging	……	……	……
Disease & pest resistance	……	……	……
Adapted to soil	……	……	……
Striga tolerant	……	……	……
Good malt and pito making quality	……	……	……
Good storage	……	……	……
Tuo quality	……	……	……
Feed quality of stalks	……	……	……
Quality for firewood	……	……	……
Ease of threshing	……	……	……

31. Indicate the level of importance of the following in assessing or choosing what variety of sorghum to grow (for male/female belonging to the household of respondent).

Trait	Very important	Somewhat important	Not important
Early maturing	……	……	……
Yield	……	……	……
Taste	……	……	……
Resistant to birds	……	……	……
Drought tolerance	……	……	……
Resistant to lodging	……	……	……
Disease & pest resistance	……	……	……
Adapted to soil	……	……	……
Striga-tolerant	……	……	……
Good malt and pito making quality	……	……	……
Good storage	……	……	……
Tuo quality	……	……	……
Feed quality of stalks	……	……	……
Quality for firewood	……	……	……
Ease of threshing	……	……	……

The Convergence of Sciences programme[1]

Background

This thesis is the outcome of a project within the programme "*Convergence of Sciences: inclusive technology innovation processes for better integrated crop and soil management*" (CoS). This programme takes off from the observation that West African farmers derive sub-optimal benefit from formal agricultural science. One important reason for the limited contribution of science to poverty alleviation is the conventional, often tacit, linear perspective on the role of science in innovation, i.e., that scientists first discover or reveal objectively true knowledge, applied scientists transform it into the best technical means to increase productivity and resource efficiency, extension then delivers these technical means to the 'ultimate users', and farmers adopt and diffuse the 'innovations'.

In order to find more efficient and effective models for agricultural technology development the CoS programme analysed participatory innovation processes. Efficient and effective are defined in terms of the inclusion of stakeholders in the research project, and of situating the research in the context of the needs and the opportunities of farmers. In this way stakeholders become the owners of the research process. Innovation is considered the emergent property of an interaction among different stakeholders in agricultural development. Depending on the situation, stakeholders might be village women engaged in a local experiment, but they might also comprise stakeholders such as researchers, farmers, (agri)-businessmen and local government agents.

To make science more beneficial for the rural poor, the CoS programme believes that convergence is needed in three dimensions: between natural and social scientists, between societal stakeholders (including farmers), and between institutions. Assumptions made by CoS are that for research to make an impact in sub-Saharan Africa: most farmers have very small windows of opportunities, farmers are innovative, indigenous knowledge is important, there is a high pressure on natural resources, the market for selling surplus is limited, farmers have little political clout, government preys on farmers for revenue, and institutional and policy support is lacking. To allow '*ex-ante* impact assessment' and ensure that agricultural research is designed to suit the opportunities, conditions and preferences of resource-poor

[1] Hounkonnou, D., D.K. Kossou, T.W. Kuyper, C. Leeuwis, P. Richards, N.G. Röling, O. Sakyi-Dawson, and A. van Huis, 2006. Convergence of Sciences: The management of agricultural research for small-scale farmers in Benin and Ghana. *NJAS–Wageningen Journal of Life Sciences* 53(3/4): 343-367.

farmers, CoS pioneered a new context-method-outcome configuration[2] using methods of technography and diagnostic studies.

Technographic and diagnostic studies

The technographic studies explored the innovation landscape for six major crops. They were carried out by mixed teams of Beninese and Ghanaian PhD supervisors. The studies looked at the technological histories, markets, institutions, framework conditions, configurations of stakeholders, and other background factors. The main objective of these studies was to try and grasp the context for innovation in the countries in question, including appreciation of limiting as well as enabling factors.

The diagnostic studies were carried out by PhD students from Benin and Ghana. They focused in on groups of farmers in chosen localities, in response to the innovation opportunities defined during the technographic studies. The diagnostic studies tried to identify the type of agricultural research – targeting mechanisms – that would be needed to ensure that outcomes would be grounded in the opportunities and needs of these farmers. Firstly, that not only meant that research needed to be technically sound, but also that its outcomes would work in the context of the small farmers, taking into account issues such as the market, input provision, and transport availability. Secondly, the outcomes also needed to be appropriate in the context of local farming systems determined by issues such as land tenure, labour availability, and gender. Thirdly, farmers also need to be potentially interested in the outcomes taking into account their perceived opportunities, livelihood strategies, cultural inclinations, etc.

The diagnostic studies led to the CoS researchers facilitating communities of practice of farmers, researchers, scientists from national research institutes, local administrators and local chiefs. The research was designed and conducted with farmer members of the local research groups. Their active involvement led to experiments being added, adapted or revised. It also made the researchers aware of the context in which the research was conducted. A full account of the diagnostic studies can be found in a special issue of NJAS[3].

Experimental work with farmers

After completing the diagnostic studies, the PhD students engaged in experiments with farmers on integrated pest and weed management, soil fertility, and crop genetic diversity, in each case also taking into account the institutional constraints to

[2] See R. Pawson and N. Tilley, 1997. *Realistic evaluation*. London: Sage Publications.
[3] Struik, P.C. and J.F. Wienk (Eds.), 2005. Diagnostic studies: a research phase in the Convergence of Sciences programme. *NJAS–Wageningen Journal of Life Sciences* 52 (3/4): 209-448.

livelihoods. They focused on both experimental content and the design of agricultural research for development relevance. Experiments were designed and conducted together with groups of farmers, and involving all stakeholders relevant for the study. The aim was to focus on actual mechanisms of material transformation – control of pests, enhancement of soil fertility, buffering of seed systems – of direct relevance to poverty alleviation among poor or excluded farming groups. The ninth PhD student carried out comparative 'research on research' in order to formulate an interactive framework for agricultural science.

Project organization

All students were supervised by both natural and social scientists from the Netherlands and their home countries. In each country, the national coordinator was assisted by a working group from the various institutions that implemented the programme. A project steering committee of directors of the most relevant research and development organizations advised the programme. The CoS programme had a Scientific Coordination Committee of three persons, including the international coordinator from Wageningen University.

CoS had two main donors: the Interdisciplinary Research and Education Fund (INREF) of the Wageningen University in the Netherlands and the Directorate General for International Cooperation (DGIS), Ministry of Foreign Affairs of the Netherlands. Other sponsors were the FAO Global IPM Facility (FAO/GIF), the Netherlands Organization for Scientific Research (NWO), the Wageningen Graduate School Production Ecology and Resource Conservation (PE&RC), the Technical Centre for Agricultural and Rural Cooperation (CTA or ACP-EU), and the Netherlands organization for international cooperation in higher education (NUFFIC). The total funds available to the project were about € 2.2 million.

CERES Training and Supervision Programme

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the CERES Research School for Resource Studies for Development which comprises of a minimum of total of 32 ECTS (European Credit Transfer System; 32 ECTS = 22 weeks of activities).

I. Orientation (15 ECTS)

- Literature Search (Wageningen University, 2002, 4 ECTS)
- Presentation Research Proposal (Wageningen University, 2002, 2 ECTS)
- Social Construction of New Agricultural Technologies
  (Department of Social Sciences/WUR, 2002, 3 ECTS)
- Agricultural Knowledge and Information Systems
  (Department of Social Sciences/WUR, 2002, 3 ECTS)
- Integrated Pest and Vector Management in the Tropics
  (Department of Entomology/WUR, 2002, 3 ECTS)

II. Research Methods and Techniques (6 ECTS)

- Methods and Techniques of Social Field Research
  (Department of Social Sciences/WUR, 2002, 3 ECTS)
- Training on Multi-Stakeholder Processes
  (International Agricultural Centre (IAC), Wageningen, 2004, 2 ECTS)
- Scientific Writing (Language Centre, WUR, 2002, 1 ECTS)

III. Seminar Presentations (16 ECTS)

- Technology and Agrarian Studies Colloquium Series
  (Department of Social Sciences/WUR, 2002, 2 ECTS)
- Internal Seminars of Technology and Agrarian Development
  (Department of Social Sciences/WUR, 2002, 2006, 2 ECTS)
- Internal Seminars of Crop and Weed Ecology Group
  (Department of Plant Sciences/WUR, 2006, 2 ECTS)
- International Seminars of Convergence of Sciences
  (WUR, University of Ghana/University of Abomey-Calavi, 2002-2005, 8 ECTS)
- Preliminary efforts at sorghum varietal improvement with farmers in north-east Ghana
  (Niamey, Niger, Consultation Workshop on Millet and Sorghum-based systems in West Africa, 2004, 2 ECTS)

Curriculum vitae

Comfort Yomle Kudadjie was born on September 20, 1970 in Accra, Ghana. In 1990, she completed her secondary education at Achimota School in Accra. For her national service she worked as a teaching assistant at the University Primary School, Legon. In 1993, she entered the University of Ghana where she pursued a Bachelor of Science Honour degree in crop science. Her dissertation was on the characterization of tomato accessions from Ghana. After her graduation in 1997, she worked for one year as a research assistant in the Department of Agricultural Extension, University of Ghana, Legon. In 1999–2001, she studied for a Master of Philosophy degree in agricultural extension at the same university, with financial support from the Sasakawa African Association. Her study investigated the adoption of improved micro-enterprise technology and how it influenced rural women's roles in Ghana. Soon after graduating she obtained funding from the Interdisciplinary Research and Education Fund (INREF) of Wageningen University in The Netherlands, and the Directorate General for International Cooperation (DGIS), Ministry of Foreign Affairs of The Netherlands, under the Convergence of Sciences Project for a PhD at Wageningen University, The Netherlands, of which this thesis is the result.

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